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This Manual of Practice has been prepared for use by local authorities and consulting engineers for the investigation of sewer systems for infiltration/inflow. This Manual discusses three areas: sewer system evaluation, sewer rehabilitation, and design of new systems to minimize infiltration/inflow.

Procedures for conducting the System Analysis and Sewer System Evaluation Study (SSES) are described in detail.

Sewer cleaning equipment and methods of sewer inspection are discussed in detail. Factors which govern the cost of conducting work are given. Rehabilitation techniques are described and an analysis of factors to be considered for each method described.

Establishment of infiltration limits for new construction is recommended at a rate not to exceed 200 gal/in.-diam/mi/day (185.2 l/cm-diam/km/day). Methods of testing are explained in detail.

This Manual of Practice was submitted in partial fulfillment of Grant No. 803151 by the American Public Works Association under the sponsorship of the U.S. Environmental Protection Agency. Companion documents also submitted in fulfillment of this project are EPA-600/2-77-017a, "Economic Analysis, Root Control, and Backwater Flow Control As Related to Infiltration/Inflow Control," EPA-600/2-77-017b, " . . . ; Appendices," and EPA-600/2-77-017c, "Sewer Infiltration and Inflow Control Project and Equipment Guide." This Manual covers a period from July, 1974 to August, 1976 and work was completed as of May, 1977.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components requires a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

Control of Infiltration/Inflow (I/I) has become a major early step in reducing the amount of untreated or poorly treated discharges of municipal sewage to receiving waters. This Manual of Practice has been prepared to provide a ready reference for those concerned with identifying and controlling I/I.

Francis T. Mayo
Director
Municipal Environmental Research
Laboratory

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SECTION I

TECHNICAL PROCEDURES FOR INFILTRATION/INFLOW ANALYSES AND SEWER SYSTEM EVALUATION SURVEY

INTRODUCTION

The basis of this manual was contributed by a Technical Advisory Committee (TAC) formed by the American Public Works Association, from among leading engineers, manufacturers' representatives and service company representatives who expressed interest in contributing their services. The TAC formed three subcommittees, each of which was enlarged to more broadly represent the field of interest, i.e., analysis and investigation, sewer inspection, cleaning and rehabilitation and new construction.

The procedures and practices reviewed in this Manual of Practice are not a "one time" panacea to sewer system problems. A sewer system cannot be rehabilitated on a one time basis and be expected to not develop additional points of infiltration or inflow. Rather, a regular preventive maintenance program should be initiated in order that a minimum of extraneous water flows can be maintained. In addition, because of the multiple factors involved, absolute certainty of cause, effect and cure cannot be assured.

Throughout this Manual the definitions of Infiltration and Inflow must be kept in mind. The effect of each upon the sewer system, treatment facility, and the means of determining the extent of contributing flow vary. In some rare cases, such as footing drains inflow may resemble infiltration, but this is not a general case.

For purposes of this manual the terms are defined as follows:

"INFILTRATION" - the volume of groundwater entering sewers and building sewer connections from the soil, through defective joints, broken or cracked pipe, improper connections, manhole walls, etc.

"INFLOW" - the volume of any kinds of water discharged into sewer lines from such sources as roof leaders, cellar and yard area drains, foundation drains, commercial and industrial so-called "clean water" discharges, drains from springs and swampy areas, etc. It does not include and is distinguished from, "infiltration."

"INFILTRATION/INFLOW" (I/I) - the volume of both infiltration water and inflow water found in existing sewer systems, where the indistinguishability of the two components of extraneous waters makes it impossible to ascertain the amounts of both or either.

The procedures involved in conducting an analysis of I/I conditions in sewer systems to meet the requirements of PL 92-500 and amendments thereto, and to conform with USEPA Rules and Regulations, can be listed as an orderly sequence of tasks. These step-by-step actions are designed to explore the scope and details of the problem and to ascertain the need for, and techniques required, to subsequently evaluate causes, effects and corrective actions.

The analytical tasks must be planned and executed to comply with Paragraph 35.927, Subpart B, of the Rules and Regulations: information submitted to the Regional Administrator should be the minimum necessary to enable a judgement as to the possible existence of excessive I/I or absence of excessive intrusion in the sewer system under study. If during the conduct of the analysis study, the engineer finds that sufficient information has been gathered to justify a judgement as to the possible existence or of excessive absence of I/I, a report should be submitted for concurrence (by the appropriate regulatory officials) at that time. The steps are graphically shown on Figure 1.

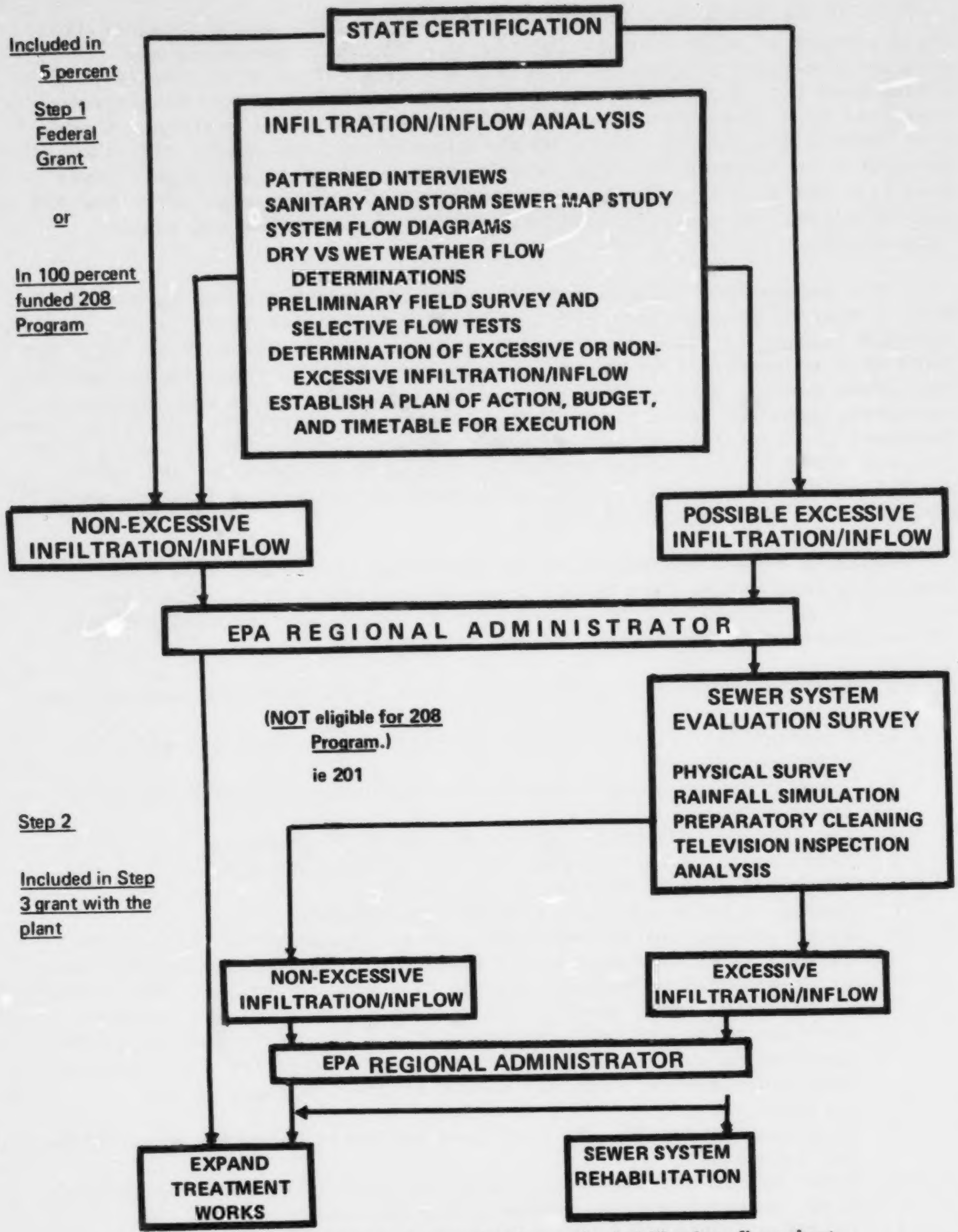
In the case of obviously non-excessive I/I conditions, where treatment plant flow data can be verified as accurate, and where the sewer system tributary to the treatment plant is not subject to excessive I/I problems, the full sequence of the listed analyses tasks need not be performed.

There are times when Section 35.927, Subpart A, would recognize the validity of decisions about excessive or non-excessive I/I conditions based on factors other than definitive cost-effectiveness. Such other factors could include treatment works construction delays and consequent cost escalation; water pollution conditions which require prompt alleviation; local public health emergencies within the sewer system or related thereto; the effects of plant and sewer system bypassing or overloading; and other relevant economic or environmental factors. If these conditions are present in sufficient magnitude, a rigorous economic analysis of alternatives may not be needed before a decision can be reached on a possible excessive I/I problem. Each case may be affected by its own indigenous conditions; each case may influence its own course of action.

The six procedural steps involved in a comprehensive analysis of sewer system I/I follow. The sequence and inclusiveness of the procedures may be adjusted as necessary to arrive at required findings and conclusions on completion of the analysis work.

Step 1: Collection of Basic Data

Analysis of I/I conditions in a sewer system must be based on a level of data accumulation appropriate to the analysis phase. If the system is shown to be possibly excessive, more detailed study will be done in the Sewer System Evaluation Study (SSES).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SEWER SYSTEM REHABILITATION

Figure 1. Steps for sewer system evaluation and rehabilitation, flow chart.

Source: State of Wisconsin Department of Natural Resources

Much of the basic data required to guide the study can be obtained from local sources if effective use is made of a carefully patterned and executed interview program. The people who have "lived with" the sewer system know its characteristics, components, capabilities and bottlenecks. They know from experience as public officials or as local residents where many defects are located, where hidden interconnections exist, what the history of performance has been, what community planning and growth needs have been and will be. They know many points of inflow, both permitted and surreptitious, and official code requirements for plumbing and sewer connections.

This information will go untapped if an interview program is not carried out. A fact-finding program will not yield full results if it is not carried out with judgement, discretion and diplomacy. The interviews must "dig" for facts with courtesy and care, but, nonetheless, with an inquisitive approach. Interviews must be patterned to contact sewer, public works and engineering personnel, covering officials and on-the-line maintenance and operation crews; treatment plant staffs; health officials; plumbing and building inspectors; planning boards; water system officials; chambers of commerce, and others. The collation, interpretation and verification of interview data are as important as the gathering of facts.

Appendix D is a questionnaire for patterned interviews used by a consulting engineering firm and is shown as an example only. The data obtained by patterned interviews and from all other sources must include, but not necessarily be limited, to the following:

1. Current population distribution data, both total and sewered, and growth factors if needed for the study.
2. Geographical, climatological, geological topographical and hydrological data.
3. Known physical condition of the sewer system, manholes and all appurtenances.
4. Age, length, materials, sizes and depths of sewers.
5. Maintenance practices, problems and system failures.
6. Treatment plant flow records and charts.
7. Pumping station and lift station flow records.
8. Water consumption and use data. It is important to distinquish between water consumption and water use. Consumption is the total water produced or pumped into the distribution system. Water use is the total water used by the customers. For customer metered services it is the total metered water. The difference is called unaccounted and consists of leakage, water used for fire fighting from hydrants etc., and may amount to 25-35 percent of the consumption.
9. Location of bypasses and overflows and their operating experiences and records.
10. Sewer system problem areas, including manhole surcharging, overflow, street flooding, basement backups, etc.
11. Existing ordinances governing inflow connections to sewers and enforcement programs and policies, as well as estimates of the

extent and significance of such inflow connections.

12. All available sanitary, storm and combined sewer system maps, plotted to workable scale or requiring such adaptation.
13. Ground water levels for all seasons, with correlation to rainfall and snow melt conditions.
14. Quality of local receiving waters and required effluent or water quality standards.

Step 2: Development of Mapping Data

No system can be analyzed until all of the sewer lines and appurtenant structures are recorded on authenticated maps. Without such basic records all of the underground facilities would be subject to blind exploration. Mapping tasks include:

A. Updating or preparation of maps

1. Augmentation of existing maps with details of new construction and revisions.
2. Preparation of new maps from as-built records, additional underground surveys and other data.
3. Sewer maps, as a minimum, should be drawn to scale and should indicate sewer sizes, direction of flow, manhole locations, as well as other major sewerage system elements: e.g., pumping stations, treatment plant, bypasses, points of overflow, etc.

B. Division of system into sub-basins

1. Establishment of rational major sub-basins, based on system layout, drainage areas, main sewers and tributary lines, system configurations and other local factors and system conditions.
2. Determination of small sub-sections when and where they are required to cover more detailed study of I/I conditions in specific parts of any sub-basin.

C. Preparation of sewer system flow diagrams and flow sheets.

D. Selection of key junction manholes for monitoring and gaging flows at points in each sub-basin which will reflect I/I conditions in constituent parts of the sewer system; choice of key manholes must be based on a critical examination of the system and the experience of local officials and the investigator.

Step 3: Monitoring and Gauging of Sewer System Flows

Dependable monitoring of flows at properly chosen junction manhole points is essential. Monitoring must be carried out at diurnal times when the data can allow differentiation between normal expected sanitary flows and infiltration and inflow volumes. Use should be made of existing sewer flow records at such central points as treatment plants and intermediate pumping or lift station wet-wells or wastewater handling equipment. Flow monitoring should be done where this mode of data gathering is required to obtain the necessary information to produce an adequate I/I analysis study. There will be times and places, however, when flow monitoring could be meaningless and expensive and should not be done because other means can adequately describe the problem.

For example, if a particular sewer system is subject to manhole overtopping, surcharged sewers, backed-up basements in such a manner that it is determinable, without question, that I/I is the problem, flow monitoring would be meaningless in the determination of excessiveness The answer to the question, "Is this portion of the sewer system excessive?" is apparent and flow in monitoring would not accomplish anything more. In addition, under the circumstances described, the accuracy of any flow monitoring that would be done would be highly questionable since depth of flow measurements are the prime means of manhole monitoring at this time.

The monitoring tasks include the following:

A. Verifying flows from plant records, pumping or lift station charts or log sheets, or from previous sewer gauging findings at the same or nearby locations involved in the current analytical procedure.

B. Gauging flows at key junction manholes, pumping stations and overflow points during hours of minimal flow, to determine the presence and amounts of infiltration volumes in various subsections of the sewer network. Gauging should be conducted at times when groundwater conditions are such that infiltration can occur and where such flow monitoring is necessary to determine possible excessive infiltration.

C. Determination of daily and hourly flow variations in a limited number of locations for the purpose of monitoring the rainfall on the flow characteristics in various sub-systems and to ascertain the quantity of I/I and differentiate between the two components.

Step 4: Field Investigations

All sewer analyses should include field investigative procedures that will augment data on the system obtained from maps, metering and gauging records and actual experiences and observations reported by interviews. Actual field investigations by a trained analyst will convert records into the realities of the sewer system being studied. The investigative tasks should include, but need not be limited to, the following goals:

A. Obtaining additional information on the physical condition of, and flow characteristics in, the sewer system under study, such as:

1. Location, number and function of bypasses and overflows.
2. Flow conditions in key manholes under varying conditions, with all manholes key-designated and described as to location.
3. Location, number and flow conditions of lift or pumping stations.
4. Treatment plant flow sheets, process configurations and metering equipment accuracies, including any flow diversions during peak flow periods.
5. Groundwater level gauging installations, to locate areas which are subjected to high groundwater conditions at all times or during certain seasonal periods.

B. Determination of types and sources of I/I by means of:

1. Limited surface and manhole inspections to ascertain the existence of possible inflow sources on private property, storm sewer and sanitary sewer juxtapositions, and inflow sources which may be found in the areas adjacent to, or in close proximity to, such locations.
2. Other field diagnostic techniques, such as limited smoke testing or flooding of selected storm sewers in close proximity to sanitary sewers to determine suspected cross connections or flow transference of flows into sanitary lines, etc., whenever deemed necessary.

Step 5: Analysis of Data

The data developed during the analysis procedures must be interpreted to ultimately determine whether the I/I problem in the community is possibly excessive or non-excessive. In order to do this, the analysis of the survey data should include the following tasks:

A. Determination of the base I/I quantities and maximum flow rates in the system and key portions thereof.

B. Computation of treatment and sewage conveyance costs including capital charges and operation and maintenance expenses for both full and partial accommodation of I/I quantities. The partial accommodation should be for the estimated flows remaining after the cost effective rehabilitation.

C. Computation of estimated costs of system rehabilitation, covering forecasted cost effective I/I reduction.

D. Establishment of a basic plan for conducting a sewer system evaluation survey coupled with the estimated costs of same for use in a cost-effective analysis and to serve as a basis for funding.

E. Preparation of cost-effective analysis for I/I control, comparing reasonable alternatives of treatment and transportation of major or minor parts of the intrusion volumes and the cost of system rehabilitation, repair or reconstruction.

Step 6: Drafting of the Analysis Report

This task will require the drafting of findings and conclusions on the presence of possible excessive I/I or the absence of this condition.

A. If non-excessive I/I conditions are found, the report must present the volume of existing intruded waters experienced in the sewer system that should be included in the design flows of the treatment facilities.

B. If possible excessive I/I is found, the report must recommend the performance of an evaluation survey, outline the plan of action and estimate the cost of the SSES.

The sequential tasks outlined above for the Collection of Basic Data, Development of Mapping Data, Monitoring and Gauging of Sewer System Flows, Field Investigations, Analysis of Data, and Drafting of the Analysis Report are intended as guidelines for the consummation of the I/I analysis. They represent a generalized approach to the engineering problem. The sequence of functions can be modified to meet local conditions and needs and inclusion of all steps may be varied as the analytical procedures are followed. The following commentaries will be of value in interpreting the specific tasks and in determining the actual analysis procedures.

o Population records and future projections may be subject to unavoidable discrepancies because of their relatively subjective nature. In many overall metropolitan areas, growth projections can be made on a fairly accurate basis but assignment of these regional growth forecasts to individual treatment plant service areas may prove to be considerably less reliable.

o Treatment plant flow data obtained as part of the data collection process and of the monitoring and gauging functions may not fully reflect actual flow conditions in the sewer system. The accuracy of existing flow metering equipment should be verified to provide validity of the records used in the analysis. Field reconnaisance observations should be used to determine if the sewer system is actually performing in conformity with pumping station and treatment plant flow records. The effect of bypassing and overflows during dry-weather and wet-weather conditions as well as in-system and off-system flow detentions must be factored into the flow records to make analysis decisions more valid.

o Sub-divisions of the sewer system plot map into minor basins for flow monitoring purposes should be made initially in terms of the large or major system division areas. Then, if further and more detailed field monitoring of flow gauging at additional key manholes are necessary to analyze I/I conditions, such key points must be designated. In choosing sub-basin points, consideration should be given to areas representing homogeneous sewer system land-use and runoff characteristics. Use can be made of community base records or information established for other purposes if they can aid in establishing rational sub-section areas. Such existing information may include data on population, dwelling units, water consumption by districts, and other factors which can be collated into the I/I study.

o It is possible that, at the completion of the data collection step and the development of mapping data actions, sufficient information will be available to warrant a conclusion that the sewer system under analysis does not have an excessive I/I problem. If this can be verified at that time, the Regional Administrator of USEPA--and involved state agency officials--should be asked to review the report and to reach a decision on this finding without further work being performed.

o Flow monitoring must be performed as part of the analysis procedures when adequate base system flow information is not available, where the minimal information required to determine treatment and transportation costs will require this operation and where the scope of the evaluation survey must be determined on the basis of known and verified flow data. Flow measurements represent an estimate only, the accuracy of which is controlled by the method used and the representativeness of the flow at the time of measurement.

o Where physical evidence of sewer surcharge conditions, bypassing or overflowing from the system is found to affect the actual flow conditions in certain areas of the sewer network, this may preclude flow monitoring in such areas. Where relief sewers or other system regulatory devices must be installed as alternatives to system rehabilitation in order to abate sewer surcharge problems, flow monitoring may be needed to design such physical facilities and ascertain their cost.

o Field investigation procedures must be varied to meet actual system needs and local conditions. The step-by-step procedures need not be carried out simultaneously or sequentially as listed. Field work must be planned and executed to meet two major objectives: The first is to determine probable sources of I/I; the second is to supplement information obtained through patterned interviews in the data-gathering phase of the analysis and to verify such information. The results of a field investigation can be useful in establishing future rehabilitation methods and costs and in determining the plan of action when the Sewer System Evaluation Survey (SSES) is undertaken. Both objectives provide needed elements of the cost-effective analysis procedure. In any event, field investigations should be limited to the facts needed to fill all information gaps which exist.

o The data analysis phase of the analysis procedure, including cost-effective analysis work and examination of treatment, transportation, sewer system evaluation and rehabilitation alternatives, should be performed only after the engineer feels that sufficient information is at hand upon which to base analytical decisions. He must be able to justify his determinations with regard to the size and character of the I/I problem, the scope and cost of any recommended evaluation survey, estimates of possible rehabilitation costs, and finally, findings on whether the system is subject to excessive or non-excessive I/I conditions.

- Other factors, either in addition to or in lieu of, a full cost-effective analysis, may determine whether a system is subject to excessive or non-excessive infiltration. Public health hazards, system physical capacity constraints which create manhole surcharges, basement backups, street flooding or large-scale bypassing or overflowing--all these conditions could be evidence that such a system is subject to excessive flow intrusions.

- If it were possible that specific parameters relating to percentage of I/I volumes in a sewer system, or some other form of criteria could be used as a guide to characterization of I/I as excessive or non-excessive, this would become a valuable general guide for consulting engineers in sewer system analyses procedures. This, however, is not now feasible or practical.

- It is possible to perform a full cost-effective analysis in almost every case on every system, but the question of whether money should be spent as part of the analysis procedure for this purpose must be considered. Since the final cost-effective analysis--as part of a SSES will be used to determine treatment plant design and to decide on the amount and method of system rehabilitation, there may be justification in waiting until the time when system evaluation surveys have disclosed all pertinent information before the cost of alternative procedures is ascertained. At that time supportable cost data can be provided by the consultant. General cost-effectiveness parameters are difficult to set; however, with care, assumed and predetermined cost-effective parameters may be used for the analysis to determine if the SSES is needed. It must be understood by all that the analysis will result in estimates. Absolute certainty is neither feasible nor apt to be cost-effective to obtain.

- Each analysis project should be planned and executed in conformity with the size of the community, the type and complexity of its sewer system, future community needs, treatment works requirements, and other indigenous conditions. In preparing a proposal for the scope of the investigation, it may be necessary in some cases to give only a general outline of a possible program, and to determine each succeeding stage on the basis of work already accomplished and the findings therefrom. Consultants should examine each system's situation carefully and determine which approach is best suited to meet the client's needs. In general, very large systems demand a flexible step-by-step approach while very small systems may be planned on the basis of a firmly established scope of work from the outset.

SEWER SYSTEM EVALUATION SURVEY (SSES)

The location of specific I/I sources in a sewer system is the second phase of the investigative procedure. It follows completion of the analysis stage and the recommendation of the analysis program. It is intended to confirm the general overall findings of the analyses program and to convert preliminary diagnoses into firm conclusions as to the presence of, location, and degree of I/I. It must also determine what I/I intrusion is excessive or non-excessive in conformity with criteria stated in PL 92-500 and USEPA rules and regulations. Definitive cost-effectiveness studies supported by the actual findings of the evaluation survey are used to estimate the amount of I/I which could be eliminated as compared to the cost of expanded physical facilities.

This conversion of preliminary findings into positive evaluation facts must be based on a detailed diagnosis of sewer system conditions. Such detail augments and supplements the more generalized data obtained during the analysis phase of an I/I study. Thus, the findings of the SSES must dictate the nature of corrective actions, their costs, the means by which I/I will be controlled, and the basis for treatment plant capacity design decisions. The evaluation survey phase will determine the extent of system rehabilitation, in a rational sequence. An accomplishment factor must be considered inasmuch as the estimates of flow which are identified as cost-effective to remain may not be 100 percent accurate.

If the findings of the analysis stage clearly demonstrates that excessive I/I does not exist in the system, and if this conclusion receives the concurrence of state and Federal EPA agencies, the evaluation phase will not be undertaken.

The evaluation survey must be planned and carried out to produce the type of authentic information that will justify the subsequent conclusions and recommendations. The depth and dimension of system evaluation must meet this criterion if it is to be the instrument for determining the actual sources of I/I, the scope of the problem, the means for correcting or alleviating it, the costs involved, and the determination of the most cost-effective means for handling the problem in each specific system. The following tasks will achieve the evaluation results required under the terms of the law and the USEPA rules and regulations.

Physical Survey of System

The need for a physical survey of any sewer system under investigation is obvious. The procedures listed below will establish a proper base for the qualitative and quantitative studies that will follow and the decisions which will translate evaluation findings into specific actions.

A. Above Ground Reconnaissance

1. Determine manhole access problems, such as easement, buried structures, traffic interference, etc.
2. Verify accuracy and completeness of sanitary sewer maps.
3. Determine proximity of storm and sanitary sewers if storm sewer maps are not available.
4. Observe inflow sources, such as roof downspouts, yard and area drains, creeks, low or inundated manhole covers and frames, and foundation drains, etc.

5. Plan for rainfall simulation tests in the form of smoke testing and/or dyed-water flooding.
6. Establish a program for uncovering manholes, improving frames and raising manholes to or above grade.

B. Manhole Inspection - see Appendix E

1. In sub-system selected key manholes, if necessary, take flow line readings, primarily during early morning hours.
2. Descend and examine condition of all manholes and lamp all lines which are required to ascertain sub-system I/I conditions.
3. Analyze data and recommend sewer sections for internal inspection to locate groundwater infiltration sources and amounts.
4. Record information on physical condition of lines and manholes as noted during manhole inspection, or lamping, as well as any I/I sources observed.
5. Determine preparatory cleaning methods and costs for those lines chosen for internal inspection. A goal of this phase of investigation should be to isolate the study area to only those areas where I/I problems actually exist. Total costs of manhole inspection, cleaning and such depend upon the size of the area studies. Thus the need to accurately delineate where problems exist.

Inflow Investigation

Infiltration caused by sewer system structure failures or defects can be classed as "accidental." These sources of infiltration are difficult to locate and expensive to correct. Conversely, inflow sources are often easier to detect and less costly to correct by structural means. Such interconnections or transferences can be located by such tasks as smoke testing and artificial flooding of storm lines, creeks or other sources of intrusion into sanitary lines. Key steps are as follows:

A. Smoke Testing

1. Conduct smoke tests in selected sanitary lines (public notification is desirable before such programs are initiated).
2. Record, both in written and photographic form, all sources from which smoke emissions are noted.
3. Visually inspect manholes suspected as a result of smoke testing, of having direct inflow connections into sanitary sewers.
4. Identify and quantify direct inflow connections to sanitary sewers.
5. Identify interconnections between sanitary and storm system as evidenced by smoke emissions from the smoke test.

B. Dyed-Water Flooding

1. Plug and flood with dyed water storm sewer sections which are parallel to or cross sanitary sewers and house service lines and which have shown evidence of smoke if nearby sections have so been tested.
2. Where applicable, flood catch basins, ditches and ponding areas in close proximity to sanitary sewers with dyed water.
3. Note sanitary flows, both before and after flooding, at points upstream and downstream of flooded areas.
4. Analyze findings and recommend appropriate sewer sections for cleaning and internal inspection.

Preparatory Cleaning

Internal inspection of lines suspected of having I/I sources requires the existence of clean lines. Debris in sewer inverts, grease accumulations on sewer barrels and heavy root infestations not only obstruct visual or video inspection equipment but they may hide or mask actual infiltration sources. Preparatory cleaning is an essential first step in any meaningful internal examination procedure. The following steps are required:

1. Clean by appropriate means and with proper equipment all sewer lines immediately prior to internal inspection.
2. Determine, if possible, all obstructions or other physical line, joint or connection conditions which could interfere with or prevent the insertion and movement of inspection equipment.

Internal Inspection

The human eye, or a camera in the form of internal inspection equipment--are the means of inspecting sewer lines. Human eye techniques are limited to manhole-to-manhole lamping in short, small diameter lines and to direct observation in large lines that can be walked or crawled. Camera inspection involves the following tasks:

1. Set up TV camera equipment or other equipment in the sewer lines under investigation.
2. Plug and flood all storm sewers in close proximity to sanitary sewers under inspection, if recommended by rainfall simulation findings.
3. Internally inspect designated footage, noting all structural defects and logging all leaks in terms of location and flow rates.
4. If services are found to be running, verify whether the flow is caused by infiltration or actual water usage.
5. Record findings on log sheets supported by photos or video tape.

Analysis of Data and Preparation of Cost-Effective Analysis

The purpose of evaluation fact-finding is to evaluate the I/I problem and to arrive at a rational decision as to the most cost-effective means of correcting or alleviating excessive intrusion conditions found in the system. It is the purpose of the following analysis-evaluative procedures to translate investigation findings into specific recommendations for positive action:

1. Assign quantitative I/I values to each source found during the evaluation survey on the basis of measurement or judgement.
2. Calculate and assign costs of rehabilitation, repair or replacement to each source of I/I based upon the costs in Section II of this Manual or from local experiences.
3. List all structural defects found.
4. List all I/I deficiencies in cost-effective order--i.e., the least costly in terms of cost versus the quantity of flow eliminated by such corrective action, first followed in sequence by succeeding cost vs. benefits actions. Table 1 is an example of such a list.

TABLE 1. COST ANALYSIS DATA

Typical Headings for Columns

Street
From
To
Length (ft)
Size (in.)
Pipe Material
Sanitary/Storm
Type Repair
Cost/Repair
Cost/Clean & Insp.
GPM Before
GPM After
GPM Reduced
% Reduction
Cost/GPM Removed
Present Value ($/ft)
Date Installed
Notes

5. On an incremental basis, compare the capital and operation and maintenance costs of transporting and treating flow from each I/I source found and listed in Item 4 with the cost of rehabilitating that source. A curve or curves comparing these functions is usually the preferable tool for accomplishing this cost-effective analysis. Figure 2 is an example of such a curve.
6. Choose the most cost-effective combination of system rehabilitation vs. treatment and transportation. Rehabilitation will only be done on those I/I sources that cost less to repair than to transport and treat.
7. Recommend the amount of I/I to be eliminated from the system by rehabilitation work and the amount that will remain in the system to be transported and treated.
8. Specify the details of the designated cost-effective rehabilitation program.
9. All costs included in the above analysis are expressed in present worth over 20 years.

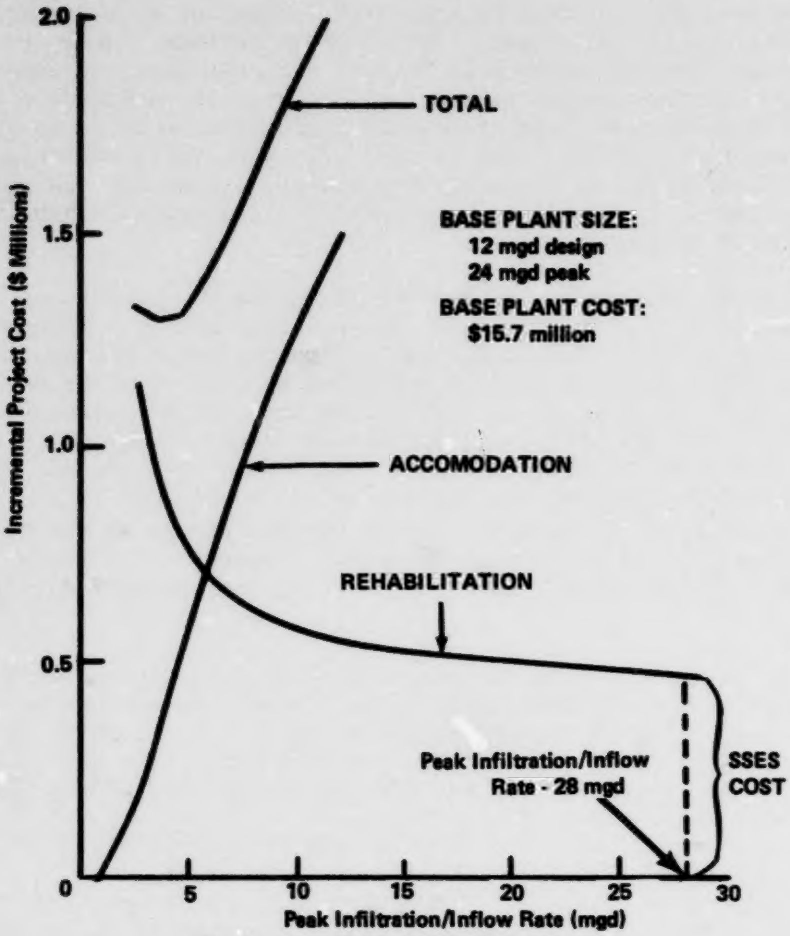


Figure 2. Cost effective analysis.

The sequential steps listed above for sewer system evaluation survey purposes must be carried out whenever the analysis--Phase I--study indicates the possibility that excessive I/I exists in the system under investigation. The procedures are required by law and regulations to allow preparation of viable conclusions and engineering recommendations on the extent of rehabilitative work required, how much system corrective action is needed, how rehabilitative work should be performed, the probable cost thereof, and the benefits to be derived. While the tasks listed are essential, their inclusion in the evaluation plan and the sequence in which they are carried out is subject to necessary flexibility of decisions based on local conditions and sewer system factors. The following comments are provided to help interpret the various tasks to be done in a sewer system evaluation survey.

o If the determination of possible excessive I/I during the Phase I work--analysis stage--is made on the basis of incomplete or inadequate flow data, the evaluation survey must upgrade these data to acceptable levels. Additional flow monitoring will be required to meet this need.

o The evaluation survey is generally thought of as being accomplished in five successive stages. The USEPA guidelines tend to recognize that these stages may not have to be carried out separately or consecutively. However, other interpretations of the guidelines indicate that these stages or tasks and their sequential performance must be adhered to without deviation. It would be helpful if sewer system investigators were allowed flexibility in accomplishing the program as long as the evaluation procedures result in a meaningful and economical rehabilitation-corrective program.

o Internal inspection for locating infiltration conditions should be justified by the findings of the physical survey. Internal inspection for locating interconnections or transferences between storm sewers and sanitary sewers should be justified by dyed water or smoke tests before they are undertaken. Due to the time of commencement of a sewer system study and prevailing groundwater level conditions, it is possible that smoke testing or dyed-water flooding may precede the physical survey. Groundwater and climatological conditions in the survey area may make it necessary to carry out all phases of the evaluation survey simultaneously or in varied sequence. However, all internal inspection work must be justified by the findings of the pre-qualification steps.

o One of the goals of an evaluation survey is to continuously redefine the extent of the area where investigative and corrective actions are needed. Even though a particular sub-basin or district has been designated for study in the analysis survey each manhole in that district may not have to be inspected. If the physical survey begins with the goal of prequalifying those areas of a sewer system which are subject to high groundwater or if infiltration is isolated by flow monitoring techniques and night flow readings, additional elimination of manholes to be covered in the district may be possible. If the determination of possible excessive I/I in the analysis phase was based on a minimal or an inadequate amount of field work and monitoring, the evaluation survey must be adequate enough to validate the overall findings and conclusions.

o Ultimately, all manholes in an area known to be subject to infiltration should be descended, inspected, lamped and evaluated for infiltration impacts. A cost-effective test should be applied to sewer sections and areas to determine if television inspection should be performed. The factors of manhole and sewer accessibility and line cleanliness should be a major consideration in such a cost-effective test.

o The search for inflow sources should be approached in several ways. Most such sources can be detected from above-ground observations and by means of smoke tests and dyed-water flooding. A determination of sub-areas containing significant amounts of inflow may be made by further flow monitoring within the chosen study areas.

o At some point in the course of the monitoring of sub-districts, it may become less expensive to locate sources of inflow by means of actual source location methods rather than to invest time and money in additional flow gauging operations. The cost of information gained through additional flow monitoring may exceed its value, if performed too extensively.

o Smoke testing should be carried out during periods of low groundwater levels to preclude any interferences with smoke emissions due to the water sealing of leaks, connections and interconnections by groundwater. In areas subject to constant high groundwater tables, dyed-water flooding may be the only way to verify interconnections and flow transference between storm sewers and sanitary lines.

o If a line has been designated for closed-circuit television inspection for groundwater infiltration and it lies adjacent to or under storm sewer sections suspected of being a possible contributor of intrusion water, flooding of that storm sewer should take place during the internal inspection. Flooding of the storm sewer prior to internal inspection may prove to be an unnecessary procedure should the line have been already designated for internal examination.

o In circumstances where the logistics can be worked out, and prior approval is obtained, internal inspection may follow directly after dyed-water flooding without the need for another additional flooding setup. Scheduling of cleaning and internal inspection in a manner that will expedite coverage of the sanitary system while the storm conduit is still flooded offers opportunities for time-saving and economies.

o Dyed-water flooding of ditches and ponding areas may not be possible because of unavailability of city water. In such cases, areas may be prepared for flooding tests prior to a rainstorm and testing can be carried out for interconnections and transference during the period of precipitation and runoff.

o Internal inspections should be carried out when the sewer lines are relatively free of flow. This may require upstream plugging of lines or the scheduling of inspections during early morning hours. Flow monitoring may be limited to carefully chosen periods when metering of interceptor sewers which are never devoid of flows is undertaken. The need for expensive internal inspection of such sewers should be proven by flow gauging before the expense and trouble of dewatering or physical inspection is undertaken.

o During the course of internal inspections, it is imperative that running house services be verified to ascertain whether observed flows through such connections are due to infiltration, inflow or legitimate water use. Such verification may be more time consuming than routine structural inspection of sewer lines.

o The final cost-effective analysis at the end of an evaluation survey may be accomplished through the use of several criteria curves--one for inflow, one for infiltration--because of the difference in duration of water intrusion phenomena from these two sources. Under other circumstances the analysis may also be carried out with a single curve which can portray the impact of the infiltration component and the inflow component when developing the treatment and transportation curve. The solution of the cost-effective problem will require variable approaches to meet variations in sewer conditions, treatment plant loadings and other local variables.

o A follow-up program, possibly as a part of the rehabilitation procedures or contract, should be required in order to assess the actual results of sewer system sealing, relining, repairs or reconstruction. Rehabilitative work cannot be considered successful unless the control of infiltration is effective over an extended period of time.

o A sewer system rehabilitation program should stimulate continuous preventive maintenance programs, rather than giving a false sense of security and lulling operations crews into spasmodic service and inspection schedules. Communities cannot expect that new infiltration points will not continue to occur, or that inflow connections will not be made either illicitly or with the knowledge of some governmental agency. Every I/I study should be augmented with an operation and maintenance manual, prepared as part of the rehabilitation program.

Alternate Courses of Action to Implement Water Pollution Control

USEPA rules and regulations allow alternatives to standard facility planning and I/I evaluation procedures. They are listed as "exceptions" in the regulation system; they are, however, more aptly described as "alternatives." Ideally, long-range planning on the part of state regulatory agencies with regard to the formulation of priority lists and funding programs should allow Step I planning processes to proceed far enough in advance so that by the time a required treatment works is at the construction funding stage this planning work will have been completed. This would allow for an orderly progression of planning, design, funding and construction, and overcome impedences in the water pollution control program.

Such long-range plans have not been in effect long enough to fully implement such an orderly procedure. As a result, many projects reach the construction funding stage before the completion of the total planning process, part of which is involved with I/I evaluation surveys.

USEPA regulations-- Paragraph 35.927-5, Subpart C--contains an alternative procedure in the form of modular construction of treatment works projects. In order to qualify under this provision in the law, it must be shown that the treatment facility for which a grant application is made will not be significantly changed by an subsequent sewer system rehabilitation program and that I/I remaining in the sewer system can be accommodated by future plant enlargement by means of modular additions to the basic design capacity. If this is done, sewer system evaluation can proceed concurrently with plant design.

Unfortunately, modular construction is not applicable in all cases. It may be especially applicable to large communities or to areas which will experience marked population growth in the near future. In communities where little or no growth is expected, treatment plants must be designed for specific flows to meet ultimate needs during the design life of the project and there may be no alternative to the procedure of withholding design decisions until the evaluation and rehabilitation stages of I/I investigations are consummated and the flows to be handled are known.

Two additional alternative procedures may be utilized to comply with the intent of the law relating to the evaluation and rehabilitation of tributary sewer systems on a proven cost-effective basis, but they are not now universally accepted under USEPA procedures. These possible alternative procedures are outlined below:

A. Sewer System Evaluation and Rehabilitation on the Basis of Extending Facility Life

1. Prepare facility plan, including I/I analysis.
2. Design and build the treatment plant to handle current and future average daily flows, with hydraulic capacity for maximum flow loadings.
3. Concurrent with plant design and construction, conduct an evaluation survey of the tributary sewer system.
4. Rehabilitate the sewer system, on a mandatory planned basis, to cost-effectively control I/I for the purpose of meeting NPDES permit requirements and for extending the useful life of the plant.

B. Sewer System Evaluation and Rehabilitation on the Basis of Matching Actual Flows and Predicted Flows

1. Prepare facility plan, including I/I analysis.
2. Design and build treatment plant to handle the estimated flow in the sewer system based on the amount of rehabilitation required to meet cost-effective criteria.
3. Conduct, concurrently with plant design and construction, a sewer system evaluation survey.
4. Rehabilitate the sewer system, on a mandatory planned basis, to cost-effectively remove I/I, matching actual flows to plant design capacity.

Feasibility of Rehabilitation Coincident with Evaluation Surveys

Strict interpretation of USEPA guidelines, in conformity with rules and regulations covering I/I investigations, require the sequential performance of the three Phases of such a program--Analysis; Evaluation; Rehabilitation--without any transpositions or consolidation of these procedures. Some consulting engineering firms and municipal engineering personnel have proposed that rehabilitation procedures, particularly internal chemical grouting, should be allowed coincident with evaluation of locations of infiltration. They rationalize that when joint defects or other physical failures are found and recorded by internal inspection or other photographic means it would be desirable to proceed immediately with the sealing of such infiltration sources. This would make it unnecessary to reclean sewer sections and to repeat internal inspection tasks, thus expediting the rehabilitative program and saving time and money. This school of thought holds that such rehabilitative costs could be reimbursed when rehabilitation work is authorized and that close control over the sealing program during the evaluation phase could be maintained to prevent excessive sealing before the cost-effectiveness of rehabilitation work has been established.

Other sewer system authorities believe that rehabilitation should not be permitted until the evaluation procedures have been completed and cost-effective analyses have demonstrated that sealing will be the most desirable and economical means of handling I/I volumes. Advocates of this sequential procedure believe that over-sealing will be avoided by this procedure. Depending upon the extent of structural damage and number of leaks found, replacement of the line or lining might be cost-effective and grouting unwarranted.

This Manual takes the position that there are convincing reasons for withholding corrective sealing until adequate cost-evaluation decisions can be made. In the future, if sewer investigative experience justifies it, some type of compromise might be feasible, with certain sealing operations permitted during the finding phase, under fund expenditure control that would limit corrective actions to a specified percentage of the total cost of the I/I investigation and rehabilitation program. This compromise might permit immediate sealing of major infiltration sources having stipulated flow rates, where groundwater intrusion is noted in the inspection program, or where obvious physical defects are found during periods when groundwater levels do not subject the sewer sections to infiltration conditions.

Explanatory Comments

This section has covered the procedural steps required in the performance of Phase I and Phase II---Analysis and Evaluation---of sewer system I/I conditions. It covers Phase III---Rehabilitation---by reference only.

Information concerning rehabilitation is provided in Section II on Technical Procedures for Rehabilitation and Repair, as well as certain matters covered in Section III on Technical Design Standards for New Construction. Therefore, all sections of the Manual of Practice must be interrelated and must be considered as complementing each other.

SECTION II

GUIDE TO CLEANING, INSPECTION, TESTING AND REHABILITATION OF SEWERS

Elimination or minimization of infiltration and inflow into public sewer systems cannot be accomplished by halfway measures. The effort involved in the preparation of sewer systems for necessary repair, replacement and/or rehabilitation will be reflected in the soundness of decisions as to which sewer sections will require such corrective actions, how much work must be undertaken, and the means by which control of excessive I/I should be carried out.

Present day sewer cleaning, inspection, testing and rehabilitation techniques have taken the guesswork out of decisions which in the past, had to be made "in the blind." By means of new equipment and technologies for sewer cleaning, sophisticated electronic and photographic devices for sewer inspection and recording purposes; advanced methods and mechanisms for sewer testing and surveillance; and innovations in sewer pipe and joints, pipe lining conduits and chemical grouting materials and mechanisms, the whole art of sewer system construction, replacement, repair and rehabilitation has been changed in the past half decade.

These improvements have been applied to the I/I control problem in the years since the APWA Research Foundation prepared its Manual of Practice on the prevention and correction of excessive wastewater intrusion into sewer systems in 1970. It is necessary to provide new "how to" information on sewer line cleaning, sewer line inspection, sewer line testing and sewer system rehabilitation, as part of the reevaluation of I/I problems. Cost data for these procedures and technologies, upon which to base cost-effectiveness decisions, are needed.

The following guidelines on these phases of I/I control were prepared by a subcommittee of the TAC which was designated to develop an overall guide covering new methods, mechanisms and materials now available for this purpose.

Generally, this section will focus on sanitary sewer collection systems consisting of 6 in. (15 cm) through 3 ft (91 cm) diameter conduits, manholes, lift stations and other related structures. Deviations from this general scope are identified.

SEWER LINE CLEANING

Cleaning Objectives:

- Remove blockages in emergency situations
- Restore full capacities and self scouring velocities (reduction of septic conditions and hydrogen sulfide generation can increase sewer system life)
- Locate breaks, offset joints, restrictions, and poor building sewer connections
- Expedite manual inspection, lamping, and flow measurement
- Prepare sewers for effective photographic or TV inspection
- Prepare sewers for internal grouting, using sealing packers, or for other rehabilitation procedures.

Adequate Cleaning Defined: Cleaning in preparation for photographic or TV inspection must be performed more thoroughly than for routine maintenance. Pipe walls must be clean enough for the camera to discern structural defects, misalignment and points of infiltration. In this phase, small amounts of debris left on the sewer invert, such as sand, stone or sewage solids, may not interfere with effective inspection except in 8 in. (20 cm) pipe where camera clearance is minimal. Root curtains and grease which would foul the camera lens must be removed.

Cleaning in preparation for internal pipe grouting, using a sealing packer, or for other rehabilitative procedures, must be much more thorough than for general sewer maintenance. All sand, rocks, gravel, bricks, grease, mud, sludge and other debris must be removed from the sewer invert to permit operation of a TV camera and sealing packers. It is usually desirable to perform the cleaning immediately prior to internal grouting operations to preclude the buildup of materials from I/I sources and the shoaling of wastewater debris. A full diameter tool or cleaning device is often required to assure adequate cleanliness and clearance for internal inspection and rehabilitation procedures.

Materials to be Removed: The bulk of sewer cleaning is involved with the removal of sludge, mud, sand, gravel, rocks, bricks, grease and roots from pipes, manholes, and wet wells. Other coarse material may be found in combined sewer lines. Removal of bricks, pieces of tile and clean sand indicates structural problems such as broken or collapsed pipe.

Cleaning Equipment and Methods: The primary tasks to be performed in sewer cleaning are intended to:

1. Dislodge materials
2. Move materials to a point of access

3. Remove materials from the sewer system.

Most cleaning techniques also require access for manpower or equipment at the downstream manhole where materials are to be removed. Some cleaning techniques require equipment access to both ends of a manhole section or sections. This requirement may be a source of difficulty.

Disposal of the material removed is an additional important consideration. In urban areas long distances to points of disposal may be required.

There are five basic types of sewer cleaning equipment:

1. Rodding machines and accessory tools
2. Bucket machines
3. High velocity water machines
4. Hydraulically propelled devices
5. Debris removal devices.

Equipment is available from manufacturers and suppliers for each classification, with characteristics ranging from light to heavy-duty application. Each class of cleaning equipment can utilize special attachments, tools, and methods to expand its capabilities so as to overlap with the primary applications of other types of cleaning devices. Cleaning equipment will be evaluated in this Manual, with emphasis on the primary application which results in more effective utilization of each technique. The evaluation should not be considered as excluding the application of any technique to other tasks involved in the great variety of sewer cleaning situations.

1. RODDING MACHINES AND ACCESSORY TOOLS

Material to be Removed:

- Most effective application is for dislodging roots and blockages
- Applicable for dislodging and transporting sludge, mud and grease, using proper tools and adequate flushing water.

Pipe Size Range:

- Generally 6 in. (15 cm) to 15 in. (38 cm), due to the tendency of rods to bend and the limited pulling power in larger diameter pipes.

Technique Advantages:

- Fast response to emergency stoppages

- Can generally reach 1,000 ft (305 m) of line
- Requires no threading; is often used for threading sewer lines, preparatory to insertion of other cleaning or inspection equipment.

Technique Limitations:

- Direct access to downstream manhole is required
- Large quantity of water is required for "brush and flush" cleaning
- Generally ineffective for transportation of heavy solids
- Technique does not remove materials from sewer.

2. BUCKET MACHINES

Materials to be Removed:

- Most effective application is for dislodging, transportation and removal of sand, gravel, rocks, bricks, and roots
- Applicable for dislodging and transporting mud and grease.

Pipe Size Range:

- Generally, 18 in. (46 cm) to 36 in. (91 cm) lines provide best use of the available power, although sizes 8 in. (20 cm) to 15 in. (38 cm) can be cleaned.

Technique Advantages:

- Provides the "iron and power" for removal of large amounts of heavy solids and roots
- Effective in large diameter pipes
- Can remove materials from sewer system
- Availability of a wide variety of accessory tools.

Technique Limitations:

- Complete access to both manholes is required
- Threading the sewer line is necessary
- Time consumed is longer than for other methods for light cleaning

- Uses heavy tools and has the power to damage pipe
- Structurally damaged pipe, offset joints, intruding service connections, and curved pipe can preclude the use of bucket tools.

3. HIGH VELOCITY WATER MACHINES

Materials to be Removed:

- Most effective application is for dislodging and transportation of sludge, mud, sand, and gravel
- Applicable for dislodging and transporting rocks and grease in pipes up to 12 in. (30 cm) diameter
- Capable of dislodging roots by using special tools in pipes up to 12 in. (30 cm) diameter
- Effective for cleaning manhole walls and benches.

Pipe Size Range:

- Most effective in sizes 6 in. (15 cm) to 15 in. (38 cm)
- Effectiveness in larger pipes is reduced except for cleaning materials from the invert.

Technique Advantages:

- Access of equipment to only the downstream manhole is required
- Not necessary to thread sewer lines; the equipment can be used for threading
- Setup is fast
- Fast method for light cleaning of debris is provided
- Ease of operation is assured
- Few operator safety hazards involved
- Low pipe damage potential is involved, except in badly deteriorated pipe
- Effective for final flushing prior to rehabilitation work.

Technique Limitations:

- Water must be available reasonably near job

- Least effective on large and heavy debris
- Can cause cavitation on open or broken pipes backfilled with sand
- Does not provide for removal of materials from sewer system.

4. HYDRAULICALLY PROPELLED DEVICES

Materials to be Removed:

- Most effective application is for dislodging and transporting sludge, mud, and sand
- Fair applicability for dislodging and transporting gravel, rocks, bricks, and grease.

Pipe Size Range:

- Generally 8 in. (20 cm) to 36 in. (91 cm)
- Best in intermediate sizes, with extreme caution required in large pipes.

Technique Advantages:

- No equipment access limitations
- Minimum equipment requirements
- Ease of operation
- Minimum operator safety hazards.

Technique Limitations:

- Large quantity of water is required at site
- Significant basement flooding is a possibility; may be used only where head in sewer will not exceed basement or drain elevations
- Not applicable to blockages resulting in surcharge conditions
- Extreme caution required when using hydraulically propelled devices in large pipes due to the large propulsive force and the hazard of getting stuck in the line
- It does not provide for removal of materials from sewer system.

5. DEBRIS REMOVAL DEVICES

- Although primarily used for catch-basin cleaning, these machines are often used for removal of most materials from manholes when other cleaning equipment is used to dislodge and transport the materials, to the access point.

Trash Pumps:

- Trailers (sometimes containing pumps and settling baffles) are frequently used to separate solid materials from cleaning water and to transport the debris to a dump site.

Cleaning Precautions

- Clean soil and pieces of broken tile observed in a manhole trough are strong indications of broken, crushed, or collapsed pipe in the upstream section. Exercise due caution prior to any cleaning.
- Eroded or corroded, or otherwise structurally deteriorated pipe may collapse during cleaning operations. Visible inspection (lamping) must be used to ascertain the advisability of cleaning. Sometimes photographic or television inspection must be used prior to cleaning in such situations.
- Full gauge cleaning tools, including hydraulically propelled devices, are subject to getting "hung up" on offset joints intruding service connections, root masses, and other obstructions. A tag cable and winch should be used whenever possible to retrieve cleaning tools and devices.
- Pipe damage is possible any time powerful cleaning equipment is used. Cleaning equipment and tools should be matched to both the job and pipe conditions to avoid damage.
- Basement flooding is possible any time hydraulically propelled devices are used. High velocity jet machines have been known to remove and expel water from non-vented closet traps.

Difficulty and Cost Factors Which Affect Cleaning Operations

- Access to manholes, terrain and traffic control limitations
- Condition of manholes - steps, cleanliness and structural integrity
- Size of pipe
- Depth of deposition in pipe

- Type of solid materials to be removed, arranged in order of increasing difficulty - sludge, mud, sand, gravel, rocks, grease, bricks, and roots. Roots are difficult to dislodge and remove completely and may be a significant factor.
- Degree of root intrusion, due to difficulty in removal
- Depth of sewer
- Amount of flow, either advantageous or disadvantageous
- Structural integrity of pipe
- Offset joints, intruding service connections, curved pipe
- Availability of hydrant water
- Degree of cleanliness required
- Differences in productivity in cleaning successive sections vs. random sections
- Requirements for transportation and disposal of solid materials and distance to the disposal site.

SEWER LINE INSPECTION

Purposes of Inspection:

- Inspect new construction prior to acceptance
- Assure sound pipes prior to paving
- Find problems in troubled areas
- Pinpoint the cause, source and magnitude of infiltration into sewer lines and appurtenant structures
- Locate improper or illegal connections and sources of inflow and evaluate the need for their elimination
- Ascertain the advisability and applicability of various methods of rehabilitation
- Estimate the amount of infiltration reduction obtainable with various rehabilitative procedures.

Inspection Techniques: There are three basic classifications of sewer inspection techniques. Each has some advantages and limitations when used for various purposes under specific sewer conditions.

1. Television Inspection

2. Photographic Inspection

3. Manual/Physical Inspection.

1. TELEVISION INSPECTION

Applications:

TV inspection provides continuous live inspection up to 1,000 ft (305 m) away in pipe sizes 0.5 to 3 ft (15 to 91 cm). The technique is well suited for determining joint conditions, root intrusion, and sources of I/I, and can be used for analyzing structural deficiencies, line and grade, and quantity of infiltration. Inspection documentation is normally made with videotape or black-and-white photographs of the TV monitor. Combination TV and photo cameras can provide in-line color photographs.

Technique Advantages:

Since TV inspection is "live," precarious conditions in the pipe can be approached with due caution. Control of the inspection is achieved by the ability to stop, back up, and position camera as desired. Problems can be discussed, analyzed, and photographed and footage noted during the course of the inspection. TV inspection provides definition of I/I sources, estimation of flow rates, and the only practical method to monitor flow from building sewers.

Technique Limitations:

- Provides black-and-white TV picture only, unless combined with in-line photographic capability.

Exhibit 1 is a typical form for recording the results of a TV survey.

2. PHOTOGRAPHIC INSPECTION

Applications:

- Provides in-line black-and-white or color photographs at equidistant intervals
- Pipe sizes 8 in. (20 cm) to 36 in. (91 cm) can be inspected
- Allows analyses of structural deficiencies
- Applicable for determining joint conditions and root intrusion.

Technique Advantages:

- Equipment cost and complexity are moderate

EXHIBIT 1. TELEVISION INSPECTION REPORT

Date ____________

District No. ________

Nearest Intersection ________________________

Foreman __________

Location ____

Area ____________

Page ____________

Code No. __________

W. O. No. __________

Vehicle No. ________

No. of Personnel _____

Fuel Used _____ Gal. ___

Sanitary ____________

Storm ____________

Flow Level S. ___ F. ____

Diameter ____________

Material ____________

Section Length ________

Total Length ________

Temp. ____________

Weather ____________

Time ____ A.M. ___ P.M. ___

Recent Rain? ________

Within 48 Hrs.? ________

Area Elevation ________

Any M.H. Infiltration? ______

Camera ___ On ___ Off ___

No. of Photos ________

Video Tape? ________

Reel No. ________

Location on Reel ______

Total Project Time ___ Hrs.

Sealing Required? ______

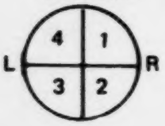
Service Connections				Root Intrusion Infiltration M.H. Infiltration Give Quadrant No.	Off-Set Joints Broken Pipe Loss of Grade or Alignment	Conn. with Roots Extended Conn. Address of Each	Grease, Scrap, Debris, or Obstructions State Type
Ftg.	Quad.	Ftg.	Quad.				

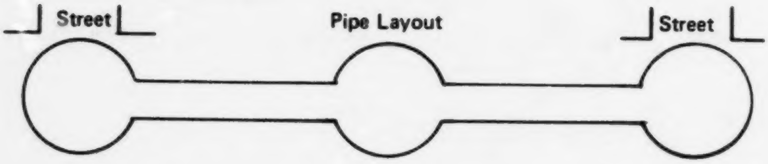
Remarks, Over-All M.H. & Step Cond., Pipe Cond., Recommendations: ______________________________

Camera Direction ____________ Are all M.H.s Accessible? ______ Approx. M.H. Depth to Invert ______

Report Prepared By ______________________________

Quadrants





- Color photographs for analysis and documentation are provided
- Provides, with a combination of TV and photo cameras, in-line color photographs which are best for discerning structural deficiencies and joint conditions at some increase in equipment complexity and camera size.

Technique Limitations:

- Effective in new construction inspection where unpredictable conditions in the pipe are not as often found as in existing pipe
- Hazardous to pull a camera into a sewer suspected of having structural problems or obstructions
- Involves the inability to position camera for optimum view of defects as problem locations are not known
- Very difficult to define I/I sources and impossible to quantify them, since water movement cannot be observed and monitored
- Roots, grease, paper and other debris can foul the camera lens without operator's knowledge
- Inspection results are unknown until film is successfully processed.

3. MANUAL/PHYSICAL INSPECTION

Lamping:

Hand-held mirrors using sunlight or a portable lamp provide simple visual pipe inspection for short distances from manholes depending on pipe size, flow, and conditions. Although the technique has obvious distance limitations, a first hand observation of pipe conditions near manholes is valuable because severe structural problems often exist due to manhole settling.

Crawling:

Although generally limited to new construction, storm sewers, or lines not in service, crawling is the most direct method for detailed, accurate inspection of an entire manhole section. The technique is applicable to lines 30 in. (76 cm) and larger. Proper cautions should be observed regarding ventilation, lighting, and protection from sharp debris.

Estimated Visible Infiltration Rates

It is desirable to quantify I/I from various sources in order to assign potential extraneous flow reduction to the available and applicable rehabilitation techniques.

Infiltration rates into manually accessible locations (manholes, wet wells) is simply estimated from experience or are captured and measured when practical. A method of the estimation of flow rates is to spend some time with a garden hose and a one-gallon container. Flow rates of 0.5, 1, 2, 4, and 8 gpm (1.0, 3.7, 7.6, 15.1, and 30.3 l/min) will take 120, 60, 30, 15, and 7.5 seconds, respectively, to fill the 1 gal (3.8 l) container. Note particularly that 8 gpm (30.3 l/min) is about the maximum flow from a garden hose. The visible estimation of flow rates is not an exact science. An observer will do well to make estimates within a factor of two, especially in the field where flow sources are considerably less defined than the flow from a hose. Estimates within 50 percent represent a "handle" on infiltration point quantification which can be used to establish the desirability of rehabilitation.

Estimating infiltration rates of sources within a manhole section from TV inspection involves other considerations. Since the size of the TV screen is fixed, a given size leak will appear much more dramatic in a small pipe than a large pipe. In addition, sewer pipe leaks often have several points of entry and can be up, down and sideways at the same time. Leaks can appear as streams, drippers, runners, trickles and boils from the bottom. A handbook containing in-line pictures of known size leaks, in several modes, taken in each size of pipe, should be developed as a training tool for infiltration rate estimators.

The important thing to remember is that a fairly good quantification of the total extraneous flow from a manhole section exists prior to in-line inspection (i.e., night flow measurements). The real purpose of the inspection is to establish approximately how much of the known extraneous flow is coming from in-line sources such as:

- Structurally damaged pipe - may require excavation/replacement
- Running building sewers - may be due to leaking joints, broken pipe, foundation drains, or sump pumps
- Leaking pipe joints - may suggest chemical grouting with a sealing packer
- Leaks adjacent to manhole - may be sealed without full section set up expense
- Leaks around improperly made service connections - may not suggest any feasible remedial procedure.

Not all of the extraneous flow from a manhole section will be observed during internal inspection, nor will individual source estimates have a high degree of accuracy. Yet, visible I/I sources can be classified and quantified to the extent necessary to determine the applicability and practicality of various rehabilitation alternatives.

Footage Measurements

Photographic and TV inspection records must log each defect or item of interest with respect to its distance from an established point. Distance is recorded in feet from the center of the starting manhole to the plane of focus of the camera. With TV inspection the following procedure is used:

1. The TV camera is focused for the clearest view of the pipe wall in the size pipe being inspected.

2. The TV camera is pulled into the line and stopped when the first pipe joint is in clear view.

3. The down-hole gear is set and the top-hole roller put in place; slack is taken out of the tag cable, and the footage meter is set at the measured or closely estimated distance from the center of the manhole to the first pipe joint.

Since footage is always measured from the center of the manhole from which the camera is pulled, it is important that the manhole be identified beyond any doubt.

Information to be Recorded

The inspection report should contain explicit information to identify positively the manhole section and starting manhole from which footage measurements are made. The report (log) should contain (but not be limited to) the following information:

Client or Owner's Name
Inspector's Name
Crew Chief's Name
Date
Time
From MH No. __________ located at __________________
To MH No. ____________ located at __________________
Direction of Measurement
Direction of Flow
Direction of North
Type of Pipe
Type of Joint
Cleanliness
Manhole Conditions
Section Length
Pipe Size

Each item of interest, structural defect, I/I source, building sewer, etc., should be logged as to location (footage and clock reference) and described as to severity or magnitude.

Terminology

Efforts to attain better levels of I/I control must be based on a uniform understanding of the "language" of the field. The following clarification of the meaning of pertinent terms used in cleaning, inspection, testing and rehabilitation of sewer systems is provided:

Areaway--A paved surface, serving as an entry area to a basement or subsurface portion of a building, which is provided with some form of drainage device that may be connected to a sewer line.

Building Sewer--The conduit which connects building wastewater sources to the public or street sewer, including lines serving homes, public buildings, commercial establishments and industry structures. In this manual the building sewer is referred to in two sections: (1) the section between the building line and the property line, frequently specified and supervised by plumbing or housing officials; and (2) the section between the property line and the street sewer including the connection thereto, frequently specified and supervised by sewer, public works, or engineering officials. (Referred to also as house sewer, and building connection).

Bypass--A pipe line which diverts wastewater flows away from or around pumping or treatment facilities - or bypasses such facilities in order to limit the flows delivered to such facilities and to prevent surcharging or adversely affecting their operation or performance.

Cellar Drain--A pipe or series of pipes which collect wastewaters which leak, seep, or flow into subgrade parts of structures and discharges them into a building sewer, or by other means dispose of such wastewaters into sanitary, combined or storm sewers. (Also referred to as basement drain).

Clean Waters-- Wastewaters from commercial or industrial operations such as cooling or process water which are uncontaminated, do not need, and could not benefit from wastewater treatment processes and which for sanitary purposes do not require disposal into public sewers, particularly separate sanitary sewers.

Collector Sewer--A sewer located in the public way which collects the wastewaters discharged through building sewers and conducts such flows into larger interceptor sewers and pumping and treatment works. (Also referred to as street sewer).

Compression Gasket--A device which can be made of several materials in a variety of cross sections, which serves to secure a tight seal between two pipe sections (i.e., "O"-ring).

Exfiltration--The leakage or discharge of flows being carried by sewers out into the ground through leaks in pipes, joints, manholes, or other sewer system structures; the reverse of "infiltration."

Foundation Drain--A pipe or series of pipes which collects groundwater from the foundation or footing of structures and discharges these waters into sanitary, combined, or storm sewers, or to other points of disposal, for the purposes of draining unwanted waters away from such structures.

Interceptor Sewer--A sewer which receives the flow from collector sewers and conveys the wastewaters to treatment facilities.

Joints--The means of connecting sectional lengths of sewer pipe into a continuous sewer line, using various types of jointing materials with various types of pipe formations that make possible the jointing of the sections of pipe into a continuous collecting sewer line. The number of joints depends on the lengths of the pipe sections used in the specific sewer construction work.

Overflow--A pipe line or conduit device, together with an outlet pipe, which provides for the discharge of portions of combined sewer flows into receiving waters or other points of disposal, after a regulator device has allowed the portion of the flow which can be handled by the interceptor sewer lines and pumping and treatment facilities to be carried by and to such water pollution control structures.

Regulator--A device or apparatus for controlling the quantity of admixtures of sewage and storm water admitted from a combined sewer collector line into an interceptor sewer, or pumping or treatment facilities, thereby determining the amount and quality of the flows discharged through an overflow device to receiving waters or other points of disposal.

Roof Leader--A drain or pipe that conducts stormwater from the roof of a structure, downward and then into a sewer for removal from the property, or onto or into the ground for runoff or seepage disposal.

Terms Frequently Used in Inspection Reports

Manhole Components:

Manhole Cover--(self explanatory).

Manhole Ring (frame)--Usually an iron casting used to top off the manhole and to act as the base for the cover.

Corbel Work--The portion of a manhole (often brick) which supports the ring and makes the transition to the vertical manhole walls.

Walls-- The vertical (usually cylindrical) portion of the manhole.

Internal Drop--Incoming sewage free-falls in the manhole to the trough.

External Drop--Incoming sewage drops to the trough in a vertical pipe outside the manhole wall.

Aprons (bench)--Standing room at the bottom of the manhole, containing the trough.

Trough--The channel at the bottom of the manhole through which sewage flows.

Invert--The exact bottom of the pipe or trough.

Invert Elevation--The height above sea level of the sewer invert.

Depth of Invert--The distance from the top of the manhole ring (street surface) to the sewer invert.

Base--The structural foundation of the manhole.

Type of Pipe and Abbreviations

Acrylonitrile-butadiene-styrene	(ABS)
Asbestos-Cement	(AC)
Brick Pipe	(BP)
Cast Iron Pipe	(CIP)
Concrete Pipe	(CP)
Corrugated Metal Pipe	(CMP)
Polyethylene	(PE)
Polypropolene	(PP)
Polyvinylchloride	(PVC)
Reinforced Concrete	(RC)
Reinforced Plastic Mortar	(RPM)
Steel Pipe	(SP)
Vitrified Clay	(VC)

Types of Sewer Joints

Asphaltic/Bituminous
Cement Mortar
Compression Gasket (O-ring, molded elastomeric seal, etc.)
Solvent Weld
Thermal Weld

Type of Debris

Sludge - organic materials
Silt - light soil
Mud - clay soil
Sand - sand, soil and grit
Gravel - smaller than 0.5 in. (1.3 cm)
Rocks - larger than 0.5 in. (1.3 cm)
Bricks
Grease
Roots
Root Curtains - growth mats that fill most of area above water level
Root Blockages - growth which fills the pipe and causes stoppage of flow

Type of Service Connections (Locate by clock reference)

Wye - manufactured pipe fitting, enters main pipe at an angle other than 90°

Tee - manufactured pipe fitting, enters main pipe at 90° angle

Saddle Tap - a device used for a cut-in connection

Intruding Service Connection - a building sewer pipe inserted into the collector sewer (street sewer); often through a hole broken in the side of the collector sewer which protrudes into the sewer.

Descriptive Terms of Pipe Defects (Locate defects by clock reference and footage)

Cracked Pipe--crack lines visible, pieces still in place

Open Crack--crack opening visible, pieces still in place

Broken Pipe--pieces displaced, some pieces could be missing

Crushed Pipe--extensively broken and out-of-round pipe

Collapsed Pipe--all structural integrity lost, pipe flattened out

Circumferential Defect--a circular peripheral defect

Longitudinal Defect--parallel to the pipe axis

Erosion--pipe worn away by the flow, generally near invert or at the flow line

Corrosion--pipe deteriorated by acid or other chemical attack, generally at crown

Offset Joint--the spigot of one section is not concentric with the bell of the adjacent section

Separated Joint--longitudinal displacement of adjacent pipe sections

Dip--a divergence in elevation

Misalignment--a divergence in line (left or right) of pipe sections

Excessive Deflection--a flattening of a flexible pipe

Describing Infiltration (Locate infiltration points by clock reference and footage)

In describing the extent of infiltration, use of descriptive words such as "seeper," "slow dripper," "dripper," "fast dripper," "runner," "fast runner," and "gusher" are nebulous and indefinite. Except for seeping and dripping infiltration points having unmeasurable flow rates, infiltration rates should be estimated as previously mentioned.

Difficulty and Cost Factors Which Affect Inspection Operations

- Location of manholes often unknown (paved over, etc.)
- Access to manholes for equipment and winches including terrain and traffic conduit
- Manhole conditions - size, steps, cleanliness, state of repair
- Availability of water for threading line

- Size of pipe - 6 in. (15 cm) to 10 in. (25 cm) is tight, and may involve equipment clearance problems; 12 in. (30 cm) to 21 in. (53 cm) is best for inspection; 24 in. (61 cm) to 36 in. (91 cm) may require special illumination and skids
- Depth of flow, flow rate and flooding conditions
- Plugging requirements vs. ability to plug or necessity to bypass
- Presence of explosive gas or combustible liquid
- Cleanliness of pipe
- Presence of root curtains, grease, soap curd and other debris could foul camera lens
- Offset joints, intruding joint materials, intruding service connections, crushed pipe and other obstructions which could prevent the passage of the camera - these conditions can be overcome sometimes by a reverse setup on a manhole section, at additional cost
- Unit cost of inspections is sensitive to mobilization of facilities and number of setups required; it is possible to televise 1,000 ft (305 m) in one direction from a single location when inspecting; successive sections; random inspection of 300 ft (90 m) manhole sections, however, is more costly
- Requirements for documentation by means of monitor photos, videotape, in-line photos, become an added cost factor
- Weather conditions such as temperature, rain or snow can affect productivity rates; snow cover can hide manholes.

SEWER LINE TESTING

Purpose of Testing:

- For new construction, to verify sewer to be structurally sound and within tightness specification requirements prior to acceptance, and to locate specific points requiring repair
- For existing sewers, to locate points of inflow, overflow, or cross connection in a sanitary sewer by means of smoke and dye tests
- For existing sewers, to quantify infiltration from a manhole section or sections by early morning flow measurements
- For existing sewers or new construction, to test individual pipe joints prior to and/or after joint sealing operations.

Detailed descriptions of infiltration, exfiltration and air pressure testing are given in Section III with regards to acceptance testing.

Testing Techniques for Lines in Service

1. Flow Measurement:

- When a sewer is below the water table, flow measurements can be made on a section or sections in early morning hours. By reducing flow measurements by the estimated nighttime sewage flow the I/I extraneous flow rate can be estimated.

- Since extraneous flow is likely to be from numerous sources, including all building sewers, and as some of the flow may be inflow from foundation drains and sump pumps, approximated extraneous flows should generally exceed 5 gal/min (18.9 l/min) per manhole section to justify further investigation. It is a fast, direct method to quantify I/I in a single manhole section or an entire subsystem.

- Flow depth recorders at key manholes can provide round-the-clock flow rate information and record responses of sewer system to rainfall.

- Flow measurements are usually made by plugging and weiring individual sections, weiring at key manholes, or taking velocity and depth measurements at key manholes.

Comment: Moderate equipment requirements. Is the fastest method to provide an estimate of extraneous flow rates. Involves a safety hazard from toxic or asphyxiating gas in manholes.

2. Smoke Testing:

- Test is performed by blowing low pressure, non-toxic, non-staining smoke into a plugged off sewer manhole section.

- Effective for detecting sources of inflow--area drains, roof leaders, abandoned building sewers, faulty connections, illegal connections and other sources. Sometimes detects structural damage, overflows and storm sewer cross connections.

- Involves minimal equipment requirements, documents system defects usually by photographs of smoke leaks, represents no safety hazards. However, considerable public relations efforts and notification of fire department is usually required.

Smoke testing should be conducted by experienced personnel who know the effects of groundwater table, frozen ground, wind, rain, trapped service connections, and snow cover on test findings.

3. Dye Testing:

- Dyed water flooding of a storm sewer section is usually performed to detect cross connections with the sanitary sewer, both man made and accidental.
- Dyed water surface flooding is used to detect inflow sources, such as area or footing drains and to simulate infiltration through porous dry soils.
- Method involves minimal equipment requirements and availability of hydrant water; documents defects usually by logging appearance of dye in sanitary sewer manhole; represents some safety hazard in retention and removal of storm sewer plugs.

4. Chemical/Biological Testing:

- Chemical and biological sampling and testing performed at key locations throughout a sewer system can indicate relationships between sanitary flows and I/I intrusions.
- In coastal areas, saline water intrusion into the groundwater may be detected in sewer samples where infiltration may be high.
- The use of fluoridation in a city water supply may produce the presence of this chemical in clean water discharges into a sewer system.

Difficulty and Cost Factors Which Affect Testing Operations

- Applicability of factors depends on type of testing being considered.
- Locations of manholes are often unknown.
- Access to manholes involves excavation if they are paved over.
- Condition of manholes involves cleanliness, presence of manhole steps and physical integrity of walls, floor and troughs.
- Pipe size and depth.
- Cleanliness of pipe during flow measurements is essential.
- Amount of flow.
- Weather conditions.
- Availability of adequate amounts of hydrant water.
- Presence of hazardous gas in manholes.

- Successive sewer sections vs. random testing of separated sections can affect unit costs.

SEWER SYSTEM REHABILITATION

Purposes of Rehabilitation:

- Preservation of pipe lines and appurtenant structures in order to assure their useful life and ability to withstand the effects of age, erosion, corrosion, settling and loading.
- Correction of existing structural deficiencies and incipient structural failure from all causes.
- Reduction or elimination of exfiltration and infiltration and, in some instances, inflow.

Deficiencies Considered for Rehabilitation:

The following collection system deficiencies are usually considered when rehabilitation decisions are made. Causes of deficiencies can range from inadequate design or construction to old age:

- Broken or crushed pipe
- Deteriorated pipe
- Deteriorated or cracked pipe or mortar joints in brick sewers and manholes
- Manhole walls, bases and troughs
- Cracked pipe
- Leaking pipe joints in street sewers
- Leaking building sewers
- Leaking manhole external drops
- Leaking or deteriorated wet wells and lift stations, regulator structures and tide gate chambers
- Defective regulators and tide gates
- Improperly supported pipe
- Deteriorated or leaking manhole walls, bases or troughs

Rehabilitation Techniques

A large number of rehabilitation techniques are available to cope with the myriad of sewer system deficiencies, conditions and restraints. When evaluating the various methods of rehabilitation, it is important to discern the proper applications, advantages, and limitations of each technique.

Technique selection should be made from applicable procedures on cost-benefit considerations or important local conditions.

Available techniques are:

- Excavation and Replacement
- Chemical Grouting
  - Acrylamide Gel
  - Urethane Foam
  - Cement
- Exfiltration Sealing
- Pipe Lining
  - Polyethylene
  - Glass Reinforced Polyester Mortar
  - Cement Mortar and Epoxy Mortar
  - Gunite
  - Concrete Shells
  - Metal
- Brick Mortar Replacement
  - Hand Troweled
  - Mechanical Extrusion

The most frequently used techniques will be evaluated in detail.

Excavation and Replacement

Excavation and replacement of existing pipe and appurtenant structures may involve pavement removal, disruption of traffic, public inconvenience, dewatering, well pointing, shoring, interference with existing utilities/structures, bypassing of sewage flows, and repaving. The total cost of replacement must be considered when comparing it with other rehabilitative techniques. For building service lines where infiltration is confirmed, the cost of investigation to allow alternate means of rehabilitation must also be considered.

Applications

- For broken, crushed and collapsed pipe
- For badly deteriorated pipe, manholes, cracked pipe, and building sewers where other rehabilitative techniques would not give the quality or permanence of replacement
- For realignment of line or grade
- For increase in size and carrying capacity of sewer
- For building service lines where connection to line was improperly made or where transfer from storm sewers to service line is confirmed.

Criteria for Proper Application

- Used when structural integrity is lost, precluding other rehabilitative procedures.
- Used when the cause of damage (corrosion, movement, loading) is identified so as to prevent reoccurrence using standard construction practices.

Technique Advantages

- Replacement is long lasting if construction and materials are matched to conditions.
- Replacement gives the highest strength rehabilitation.
- Replacement presents the opportunity to increase conduit size while correcting deficiencies.

GROUTING

Pipe grouting refers to the placement of a material (grout) on, in, or outside of sewer pipe joints for the purpose of preventing exfiltration of sewage or infiltration of water, soil and roots through defective joints.

One objective of pipe grouting is to stop groundwater and soil infiltration in order to prevent road surface cave-ins and eventual collapse of the pipe itself through loss of bedding material. Since 1963, pipe grouting has become increasingly important as a means of reducing sewage treatment plant load due to groundwater infiltration into sanitary sewers.

Manually accessible storm and sanitary sewers were first grouted by the hand application of quick setting hydraulic cement to joints and lift-holes. This technique is still used where applicable, but usually in preparation for the injection of chemical grout to provide a more efficacious seal. Hydraulic cement is difficult to apply to actively infiltrating leaks, and sometimes must be done during the dry season.

External pipe grouting with cement, bituminous materials, sodium silicate/calcium chloride, acrylamide gel, and other grouts was started about 1957. The technique involves jetting an injection pipe from ground level to the vicinity of the leak and pumping grout into the area. The procedure is somewhat "hit-and-miss" and quantities of grout are likely to enter the pipe through the leaks.

Internal pipe grouting with mechanical packers using cement paste grout was attempted in the late '50's. A thick paste consisting of cement and additives to achieve a very low slump was placed between compressing squeegees and pulled through the line. It was necessary to plug or bypass the section under repair. Sealing results were uncontrollable. Sanitary sewers have service connections, off-set joints, and frequent structural problems which generally preclude application and practicality of this procedure.

Sealing sewer pipe leaks by the exfiltration of slurries containing sodium silicate was attempted in the early '60's. Exfiltration sealing of leaking sewers involves plugging-off or bypassing the section under treatment. It is necessary to surcharge the section with slurry to at least 4 ft (1.2 m) above groundwater level to achieve 2 psig (0.07 kgf/cm^2) exfiltration differential. Plugging, bypassing, and surcharging often involve severe impracticalities and the danger of flooding service connections. Although good results have been reported under limited conditions, only partial or temporary benefits have resulted from most exfiltration sealing applications.

Internal sealing of pipe joints with pneumatic packers using acrylamide gel grout was introduced commercially about 1960. By the mid '60's, transistorized electronics made possible the production of small, rugged, waterproof, high resolution, self contained closed circuit television (CCTV) cameras. Inspection and joint-by-joint sealing in sanitary sewer pipes as small as 6 in. (15 cm) diameter became feasible with the camera/packer combination. Process control is inherent as infiltrating joints can be located and visibly inspected after sealing. The system enjoys certain practicalities: packers are made smaller than the sewer pipe in order that they can negotiate off-set joints and some intruding service connections. Also, the packers are in the form of a hollow cylinder which permits normal sewage flow during sealing operations without plugging or bypassing in most cases.

A flexible seal is made outside of the pipe when using the AM-9 * type chemical sealant. Pipe grouting with acrylamide gel has been the most widely used grouting process since the early '60's and will be discussed in detail.

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* Registered Trademark of American Cyanimid Company.

Internal sealing of pipe joints with pneumatic packers using urethane foam grout was introduced commercially about 1972. The mechanism of sealing is to place a foamed gasket in the joint area. Mechanical locking of the expanded foam in the joint and a limited degree of adhesion provides retention. Pipe grouting with urethane foam will also be discussed in detail.

Limitations to Grout Sealing

- Improperly supported pipe may continue to move after joints are sealed.
- Grouting is not a structural repair. Broken, crushed, and badly cracked pipe are candidates for excavation/replacement, and internal pipe grouting with a sealing packer should not be attempted.
- Sealing packers can be used only where the inflatable sleeves straddle the leak point and make continuous contact with sound pipe on each side.

Exhibit 2 is an example of a form which can be used to record the results of a grouting program.

Acrylamide Gel

Acrylamide Gel is a mixture of two organic monomers: Acrylamide and N,N - Methylenebisacrylamide. When a dilute aqueous solution (usually 10 percent of batch weight) is properly catalyzed, gelation occurs by a polymerization-crosslinking reaction, forming a gel. B-Dimethylaminopropionitrile (Catalyst DMAPN) is a somewhat caustic liquid used as an activator for the reaction (usually 0.5 percent to 1.5 percent of batch weight). Ammonium persulfate (AP) is a strong oxidizing salt, used as the initiator that triggers the reaction. The induction period (gel time) begins with its addition. The ammonium persulfate is added as an aqueous solution (usually 0.5 to 3 percent of batch weight).

Gel time can be controlled from 5 to 500 seconds by the weight percent of DMAPN and/or ammonium persulfate used. A gel time of approximately 20 seconds is commonly used in sewer grouting. Longer gel times are generally used in structural waterproofing, with lower flow rates and deeper penetration.

A 10 percent solution of Acrylamide gel has a specific gravity of 1.04 and a viscosity of 1.2 centipoise (water = 1.0 centipoise). The grout can penetrate small leaks and cracks through which ground water is flowing.

Since the grout is about 87 percent water at the outset, it is not adversely affected by the presence of water other than by dilution. When injected into sand or sandy soil, the grout tends to displace rather than to mix with the ambient water. When injected into coral sand, gravel, or rock, dilution can render the grout ineffective, especially in the presence

EXHIBIT 2. TELEVISION SEALING REPORT

Date ____________________
District No. __________
Nearest Intersection
Foreman ____________
____
Location
____

Area _______________
Sanitary _______________
Temp. __________________
Camera ___On __Off __
Page _______________
Storm _______________
Weather _________________
No. of Photos ________
Code No. ___________
Flow Level S. _____ F. ___
Time _____A.M.___P.M. ____
Video Tape? _________
W. O. No. ___________
Diameter ______________
Recent Rain? _____________
Reel No. ___________
Vehicle No. __________
Material _______________
Within 48 Hrs.? ____________
Location on Reel ______
No. of Personnel ______
Section Length __________
Area Elevation _____________
Total Project Time__Hrs.
Fuel Used _____ Gal.____
Total Length ___________
Any M.H. Infiltration? _______
Date of TV Inspection _______________

Footage of Joints or Repairs Made If Other Than Joint Renovation

Ftg.	Gal.	Ftg.	Gal.	Ftg.	Gal.

Injection Time Standard_____Minutes _____Seconds
Cure Time Standard _____Minutes _____Seconds
Gel Time _____Minutes _____Seconds
Injection Pressure ________psi
Packer Inflation Pressure ______psi
Was Root Inhibitor Grout used? _______________
Was Excess Gel Removed After Repair? __________
Operation? ____________________________
Total Chemical Injected ________ gal.

Comments

Chemicals And Mix Information
(As appropriate for type of grout used.)

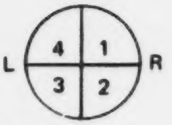
Protective Clothing and Gear must be used when mixing or during any exposure to Chemicals.

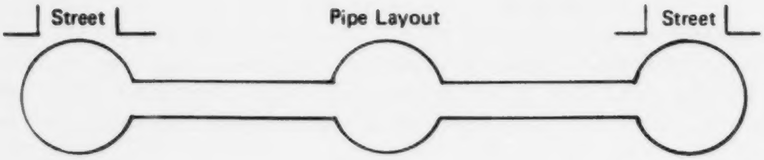
. . . . . .

Don't just think Safety!! Keep an Eye on it !!!

Camera Direction______________
Are all M.H.'s Accessible? __________
Approx. M.H. Depth to Invert _____
Report Prepared By ___________

Quadrants





of moving groundwater. The use of a higher grout concentration and thickening additives can overcome these problems.

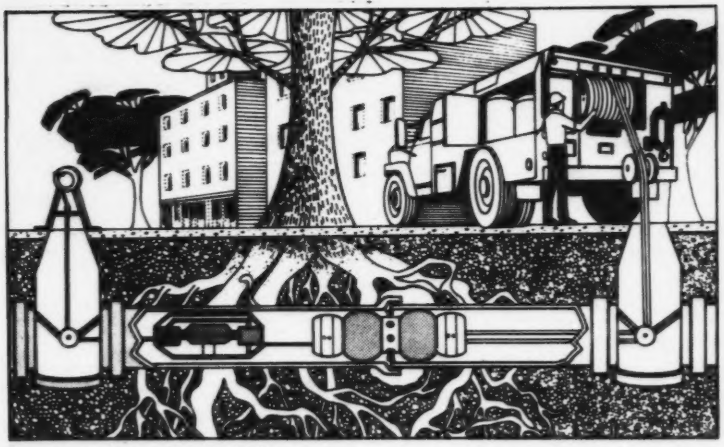
Some areas have clay soil with such low permeability as to be considered ungroutable from a soil stabilization viewpoint. When acrylamide gel is used to seal sewer pipe joints, soil makeup in the trench surrounding the pipe (backfill) rather than local soil permeability controls the grouting process. Appurtenant structures such as manholes, however, are likely to be backfilled with local soil. Experience and a knowledge of local conditions are more valuable than hard and fast rules for the application of acrylamide grout.

Acrylamide gel grout has an application history dating from 1960.

Internal grouting of structurally sound pipe joints is the most widely used application. Pipe joint sealing is accomplished with packers using the following method, basically described as follows:

Placement:

1. A hollow metal cylinder having inflatable rubber sleeves on each side of a center band is positioned on a pipe joint as shown in Figure 3.



Source: American Cyanimid Co.

Figure 3. Internal grouting with hollow metal cylinder flanked by inflatable rubber sleeves placed over pipe joint.

2. Air pressure is introduced underneath the rubber sleeves causing them to expand and seal against the internal pipe wall on each side of the joint to be sealed.

3. Chemical grout is pumped into the void created between the two inflated sleeves.

4. The chemical grout and the initiator mix together in the void and are pumped out through the joint leak into the soil outside the pipe.

5. The chemical grout displaces groundwater and saturates the soil surrounding the pipe. After a period of time (usually less than a minute) gelation of the chemical grout occurs, forming an impervious mass of sealant outside the defective pipe joint. The packer is then deflated and moved to the next joint.

Packer units may be obtained with a joint testing capability. Air is used, with a drop in air pressure indicating the need to seal the joint. Packers may also be obtained with an inflatable center section to assist in pushing the grout out and minimize use of the grout.

A closed-circuit TV camera is used to remotely position the packer on the pipe joints and to visibly inspect each joint prior to and after the sealing operation. The TV camera and packer are pulled by cables through a sewer section from manhole to manhole.

Internal grouting of pipe having minor bell shears and circumferential beam breaks can generally be achieved provided that the packer sleeves inflate and seal against sound pipe on each side of the defect.

Leaking manhole walls, bases, troughs, and cracks in wet walls and lift stations can be sealed under the proper conditions. Special techniques are required which usually involve pumping chemical grout out through the leak or drilling a hole for that purpose. This is often referred to as "structural waterproofing."

Acrylamide gel can be used to stop running water prior to cement grout, gunite, or cement mortar application.

Leaks in building sewers can often be sealed with acrylamide gel. Since access and size, usually 4 in. diameter (10 cm) prevent the use of conventional camera packer procedures, special techniques are used. Frequently, the entire building sewer is pumped full of grout causing exfiltration of grout through the various leaks. After gelation, it is necessary to clean the excess grout from the building sewer with a rodding machine.

Manhole to external drops can be sealed by methods similar to those described for building sewers.

Criteria for Proper Application of Grouts

- Adequate structural integrity must exist in the pipe or structure considered for sealing
- Soil conditions surrounding the pipe or structure should allow for effective sealing
- Pipe must be thoroughly clean to permit proper operation of a sealing packer
- Pipe must be free of obstructions and intruding service connections to permit passage of the sealing packer through the pipe lines.

Acrylamide grout should not be subjected to prolonged dry soil conditions or exposure to dry air. Resistance to dehydration can be achieved by using an admix of 10 percent calcium chloride flake in the grout formulation.

Technique Advantages

- Most leaks in manually accessible pipe or structures can be sealed, using special equipment and methods when necessary
- Acrylamide grout is an effective method of sealing leaks in pipe joints. (The seal has a high degree of flexibility and therefore sealed joints can accept movement).
- Sealing creates an impervious mass outside the joint by saturating and stabilizing the backfill, therefore, continued movement of improperly supported pipe may be arrested
- Leaks in building sewers, manhole external drops and stubouts can usually be sealed with increased quantities of acrylamide gel
- Low viscosity chemical grout can penetrate small cracks for structural sealing against high pressures
- Variable and controllable gel time is useful in penetrating large distances for structural waterproofing
- Acrylamide gel is easy to clean up. Gel left in sewer pipe will be macerated at pumping stations.

Urethane Foam

Urethane foam is a liquid prepolymer containing solid materials constituting 82-88 percent of its weight and having a viscosity in the 300-350 centipoise range. When mixed with an equal quantity of water containing an accelerator (0.4 percent concentration), the hydrophilic polymer initially foams and then cures to a flexible cellular "rubber."

When the prepolymer reacts with water, foaming and expansion commences with steadily increasing viscosity. After a period of time (foam time) the grout is forced into the leakage site while it has sufficient mobility to penetrate the leak, but will not readily flow out of the site into the surrounding soil or washed-out cavity beyond. Foam time ranges from 45 seconds at 40°F (4°C) to 15 seconds at 100°F (38°C).

After the grout is forced into the leakage site (end of foam time), cure time begins. During this period, the grout solidifies and forms a cellular rubber-like material of sufficient strength to become a barrier against water.

Temperature of the grout and water is the variable that affects cure time. Cure time ranges from 15 minutes at 40°F (4°C) to 4.6 minutes at 100°F (38°C), when reacted by water only. Cure time ranges from 5.5 minutes at 40°F (4°C) to 2.6 minutes at 100°F (38°C), when reacted by water with 0.4 percent accelerator.

When cured, urethane foam is held in place at the leak site by a combination of chemical and mechanical adhesion. Physical properties of the cured material depend on the degree of confinement during the cure period. Density of 14 lbs/ft^3 (224.3 kg/m^3), tensile strength of 80-90 psi (5-6 kgf/cm^2), and elongation of 700-800 percent for the cured material are published by the manufacturer. The cured material is resistant to most organic solvents, mild acids and alkali.

Wet or dry cyclic conditions do not substantially affect the grout due to the fact that it contains only 15 percent solvent in the prepolymer, and when fully cured and dry will likewise suffer a linear shrinkage of only 15 percent. Shrinkage has little effect on the gasket formed because of adhesion to the joint/leak interface.

Urethane foam grout has an application history dating from 1970.

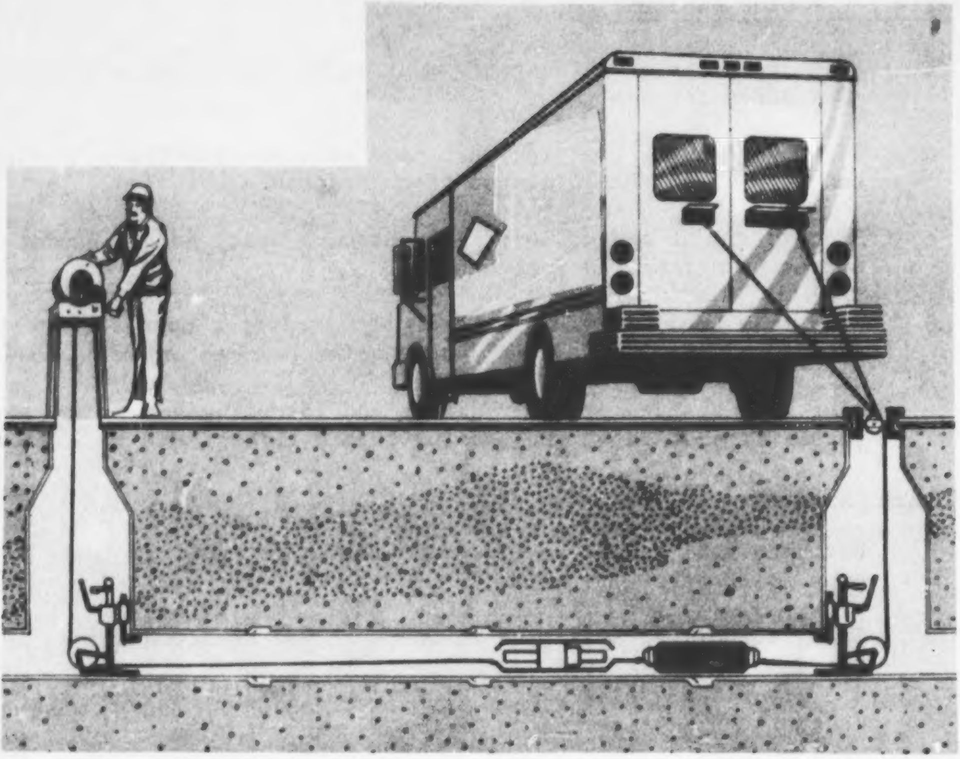
Internal grouting of structurally sound pipe joints is the most widely used application. Pipe joint sealing is accomplished with a packer which is basically described and operated as follows:

Placement:

1. A hollow metal cylinder having inflatable rubber sleeves at each end and in the center is positioned on a pipe joint or other defect point. The three inflatable sleeves are covered by a continuous outer sleeve to which the grout will adhere. Figure 4 shows a typical grouting unit.

2. Air pressure is introduced underneath the end sleeves, causing them to expand and seal against the internal pipe wall on each side of the joint to be sealed.

3. A quantity of prepolymer and water is injected (and mixed) into the void created between the two inflated packer end portions and "foam time" begins.



Source: Cherne Industrial, Inc.

Figure 4. Sleeve packer for use with 3M Elastomeric grout.

4. At the end of foam time (35 seconds at 60°F (17°C)) the center element is expanded against the joint, forcing the grout into the joint/leak and "cure time" begins.

5. At the end of cure time (4 minutes at 60°F (17°C)) the grout has developed sufficient strength to become a barrier against water. The packer is then deflated and moved to the next joint. Packer units may be obtained with a joint testing capability. Water is used as the pressure medium. Loss of water indicates a need to seal the joint.

A closed-circuit TV camera is used to remotely position the packer on the pipe joints and to visibly inspect each joint prior to and after the sealing operation. The TV camera and packer are pulled by cables through a sewer section from manhole to manhole.

Internal grouting of pipe having minor bell shears and circumferential beam breaks can generally be achieved, provided that the packer sleeves inflate and seal against sound pipe surfaces on each side of the defect.

Leaking manhole walls, bases, and troughs can be sealed under proper conditions. Special techniques are required which usually involve injecting the grout into the leak.

Criteria for Proper Application

- Adequate structural integrity must exist in pipe or structure considered for sealing
- Soil surrounding the pipe must have adequate stability to support the pipe after the joints or other defects are sealed
- Pipe joints or cracks must have adequate space for mechanical retention of applied sealant
- Pipe must be thoroughly clean to permit proper operation of a sealing packer. Roots and sand must be removed prior to sealing.
- Pipe must be free of obstructions and intruding service connections to permit passage of the sealing packer through the pipe line.

Technique Advantages

- Urethane foam can be an effective method for sealing leaks in pipe joints
- The grout can be effective in both wet and dry conditions
- The grout has a high degree of flexibility and can thus accept movement
- The grout is not sensitive to backfill conditions.

Grouting of Manually Accessible Pipe

Manually accessible pipe can be sealed using either sealant with the use of appropriate equipment. The sealing equipment is set up directly over the joint for small diameter pipes. For larger pipes and manholes holes are drilled in the pipe wall and the grout is injected.

Internal grouting of manually accessible pipe using epoxy for the purpose of adding strength to the existing structure can be used. (1) A hydraulic cement is applied to the crack or joint to temporarily stop the intrusion of water. Into this hydraulic cement are placed T-type orifices that will allow later entry of the two-part epoxy resins.

After the curing of the hydraulic cement is complete (usually a few seconds to a few minutes), a two-component, 100 percent solid epoxy paste is applied over the hydraulic cement. This paste has gel time of 15 minutes to one hour, depending upon temperature.

These relatively new epoxies contain both mechanical and thermal curing properties and are non-toxic in their mixed form, eliminating the need for special ventilating equipment.

After the epoxy paste has cured, water will only enter the structure through the inserted orifices. At this point, an epoxy pumping system is used to inject resin through the T orifices. The resin must be injected at 28 to 29 psig (1 to 1.4 kgf/cm^2) greater pressure than the intruding water, and into the joint or crack. The injection resin has a cure time of approximately 45 minutes at 55°F (13°C) and one hour at 32°F (0°C). This does not appear to be a limiting factor because water will not displace the non-cured epoxy nor will it become soluble, even at the highest temperatures encountered.

The operator of the pumping equipment can avoid filling large voids on the outside of the structure by simply reading back pressure on the gauges affixed to the pumping equipment.

The cured epoxy (100 percent solid material) remains exactly in the form in which it was injected. There is no shrinkage or expansion of the material.(1)

Pipe Lining

Several factors are applicable to both polyethylene and glass reinforced polyester mortar pipe lining and systems. These are:

Applicability

- Extensively cracked pipe
- When excavation/replacement is intolerably inconvenient or impractical
- When the existing pipe cannot be taken out of service or bypassed during rehabilitation.

Criteria for Proper Application

- Prior to a decision on the applicability of rehabilitation, the existing pipe must be internally inspected to ascertain structural conditions, obstructions, offset joints, intruding service connections, line and grade. A proofing tool, preferably a rigid nose cone of sufficient size and length, should be pulled through the existing pipe to prove the feasibility of inserting the proposed liner diameter.
- The existing pipe must be in good enough condition to allow cleaning prior to lining.
- Generally, slip-lining is most feasible when a considerable length (2 or 3 manhole sections) can be lined from a single excavation. When more than two excavations are required in a manhole section, replacement of the section is usually indicated.

Technique Advantages

- Normal sewage flow can be maintained during liner insertion.
- Liners are corrosion resistant.

Technique Limitations

- Cleanliness, condition and alignment of existing pipe are critical considerations.
- Building sewers are difficult to cut in and connect.

1. Polyethylene:

Insertion lining of existing sewers with polyethylene pipe is performed by pulling a continuous length of butt fused liner pipe into an existing sewer through an excavation point. The excavation is made directly over the existing line and has sufficient width to allow the entry of workmen. Sheathing and bracing requirements depend on depth and ground conditions. The length of the excavation is determined by the depth of the sewer and the bending radius of the sewer liner pipe. The bending radius is usually 30-50 times the outside diameter of the liner pipe. The selection of the radius is based on the need to avoid kinking of the liner pipe and to reduce frictional forces at the entrance of the existing sewer. The trench is sloped gradually from the ground surface to the top of the existing line. Excavations are chosen at points where a dig up is indicated and/or where the longest pull can be made in each direction from a single trench.

A winch of sufficient power is used to pull the liner into the existing pipe from as far away as practical. Usually there is sufficient annular clearance around the liner to permit normal sewage flow during installation without need for bypassing or disrupting service on the line.

Building sewers, if any, must be cut in and connected in a manner which will prevent infiltrating groundwater in the annulus from entering the liner at the service taps. This is achieved either by directly connecting the building sewers to the liner or by grouting the annulus using techniques which prevent grout from entering the liner pipe and the building sewer.

Grouting the annulus for structural support is generally not necessary if the liner wall thickness is strong enough to withstand anticipated loads in the event of existing line collapse. When the annulus is not grouted, an efficacious seal must be made at each manhole interface to prevent groundwater entry.

Applicability

Polyethylene line rehabilitation is applicable for:

- Steadily deteriorating sewer pipe such as lines having shallow grades, septic conditions and corrosive liquids
- Lines in unstable soil conditions
- Pipes having massive and destructive root intrusions.

Criteria for Proper Application

- Liner wall thickness must be chosen to withstand anticipated external hydraulic loads and trench loads in case the existing pipe collapses. The impact and advisability of annulus grouting influence the wall thickness determination.
- The influence of cold weather on liner stiffness and thermal expansion/contraction must be considered when scheduling installation.

Technique Advantages

- The liner has widely spaced, 38 ft (11.6 m) heat-fusion joints which prevent joint leakage and root intrusion
- The liner has a high flow factor which may increase the flow capacity of the pipe line
- Since the liner is capable of deflection and movement without breaking, it is an attractive method for rehabilitation of lines laid in unstable soils when replacement would have doubtful permanence
- Long lengths may be inserted
- Flexibility permits insertion through gradual changes of direction.

Technique Limitations

- Excavations must be large enough to provide adequate bend radius (30 D) during installation. NOTE: If more than two excavations are required in a manhole section, replacement of the section is usually indicated.

2. Glass Reinforced Polyester Mortar:

Insertion lining of failing sewers with fiberglass reinforced plastic mortar pipe is performed by jacking or drawing liner sections, usually 20 ft (6.1 m) into the existing pipe line. The liner sections are joined by O-ring sealed inverted bell and spigot joints which maintain a uniform outside diameter.

An excavation is made directly over the existing line. The working pit must be long enough to accommodate the sections of liner and the jacking equipment. A pit of approximately 26 ft (7.9 m) can be used if the liner sections are pulled into the existing line. Sheathing and bracing requirements depend on depth and ground conditions. The top half of the existing pipe is removed in the working pit to permit insertion of the liner sections. It is easier to pull the liner pipe upstream against the flow because fragments lost during removal of the upper portion of the existing pipe and debris from the access pit tend to get into the line and, due to its light weight, the liner has a tendency to move with the flow, creating the possibility of coming disjointed going downstream.

Normal sewage flow can continue during the entire procedure. Grouting the annulus between liner and existing pipe is generally not necessary. When the annulus is not grouted, an efficacious seal must be made at each manhole interface to prevent groundwater entry.

Applications

- It is generally more applicable to large lines 21 in. (53 cm) and up having no sevice connections.

Criteria for Proper Application

- Generally, lining is most feasible when a considerable length of pipe can be lined from a downstream working pit.

Technique Advantages

- Reinforced plastic mortar pipe has high strength, and is hydraulically smooth
- Working pit length requirements are minimal.

Technique Limitations

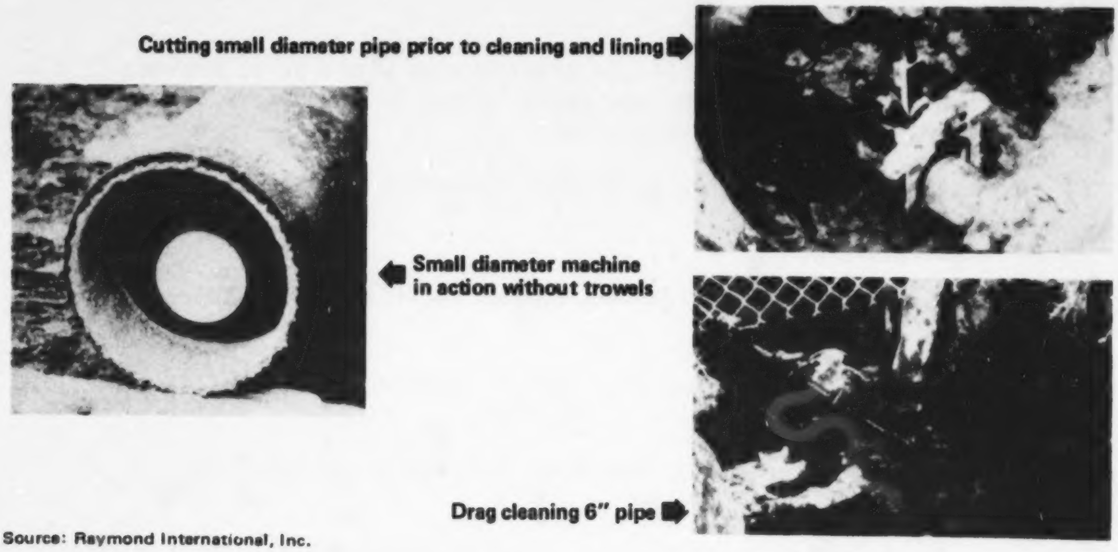
- There is some flow reduction from inverted bell joints.
- Semi-rigid material has limited ultimate strain capability.

3. Cement Mortar and Epoxy Mortar

Cement and epoxy mortar linings can be centrifugally machine applied to the interior surface of existing pipes. Lining thickness requirements are dependent on the degree of deterioration. Thickness may range from a minimum of 0.125 in. (0.3 cm) to a maximum of 0.75 in. (0.9 cm) for a single pass of the lining machine. Figure 5 shows such an application.

Applications

Mortar lining is applicable to deteriorated round pipe which is structurally sound. Mortar linings are most often applied to concrete pipe, and sometimes applied to brick pipe.


Cutting small diameter pipe prior to cleaning and lining
Small diameter machine in action without trowels
Drag cleaning 6" pipe

Source: Raymond International, Inc.

Figure 5. Application of cement mortar and epoxy mortar.

Cement mortar is generally used to rehabilitate sewer pipes 16 in. (41 cm) in diameter or larger which have deteriorated from severe erosion or from corrosion by chemical attack. It is not used to prevent corrosive attack.

Epoxy mortar is mainly used to prevent deterioration of sewer pipes 24 in. (61 cm) in diameter or larger from a corrosive atmosphere or acidic flow. These conditions may be found in both domestic and industrial waste lines. Epoxy may also be applied as a finish coat to cement mortar. The materials must be carefully controlled and mixes adjusted for local conditions such as temperature.

Criteria for Proper Application

o Sewage flow must be by-passed and service suspended in the section being lined. The pipe surface must be free of loose material and the surface should be treated as necessary to remove traces of oil, scum, bacterial growths, or other substances.

o Water standing in the pipe must be removed. Infiltration of any type must be stopped prior to lining application.

o Damp pipe is permissible for both cement mortar and epoxy mortar lining so long as water droplets or water films are not apparent on the pipe surface.

o Ambient temperature must be greater than 50°F (10°C).

Technique Advantages

- When used to rehabilitate deteriorated pipes or to prevent future chemical attack, cement and epoxy mortar lining offers a moderate cost alternate to replacement

- The technique involves minimal reduction of pipe diameter.

Technique Limitations

- Sewage flow must be by-passed and service suspended during application

- Infiltration through pipe joints, pipe walls and building sewers must be stopped prior to application

- Cement mortar alone should not be used to prevent chemical attack

- Epoxy mortar should not be mixed or applied below 50° F (10° C).

Difficulty and Cost Factors which Affect Rehabilitation Operations

Rehabilitation difficulty factors are very complex. Every sewer system deficiency and applicable rehabilitation technique is cost sensitive to different considerations. Complex difficulty/cost factors must be considered in any rehabilitation decision.

- Location of job determines equipment mobilization costs, local labor rates and expense of crew accommodations.

- Weather conditions (cold temperature, rain, snow) have a significant effect on production rates, not because of crew discomfort, but for reasons such as: Inability to locate manholes under snow cover; reduced mobility of vehicles and equipment; inability to park equipment on street; inability to enter manholes because of high water flooding; freezing, stiffening, and longer cure time of rehabilitation materials.

- Access to manholes, including locating and exposing them if paved or covered over, as well as topography and terrain for vehicle and equipment access are important cost factors.

- Manhole conditions, including size, clear opening, depth, steps, inside/external drops, hazardous gas and cleanliness all affect rehabilitation practices.

- Pipe size has a significant impact on certain rehabilitation procedures. Small pipes 6 and 8 in. (15 and 20 cm) require heavier, specialized equipment with clearance limitations. Intermediate pipes 10 to 21 in.(25 to 53 cm) are mostly sensitive to the increase in materials consumption with size. Large pipes 24 to 36 in. (61 to 91 cm) also require heavy specialized equipment, and often necessitate removal of the top portion of a manhole for access.

- Depth and rate of flow, ability to plug the line, or the necessity to by-pass flows are important considerations

- Cleanliness of the pipe and the rate of infiltration or washdown of debris into the rehabilitation area determine the necessity for additional cleaning

- Pipe conditions such as offset joints, intruding joint materials such as cement and tar, intruding service connections, crushed pipe, or other conditions which could prevent the passage of grouting equipment and liners, or require reverse set-ups or excavations, are of critical concern in determining rehabilitation costs

- Rehabilitation of successive sections is more efficient on a unit basis than random section repairs due to mobilization and set-up expenses

ROOT CONTROL (A comprehensive discussion of root control is found in "Economic Analysis, Root Control and Backwater Flow Control as Related to I/I Control."

Purpose of Root Control/Removal

- To prevent root blockages

- To restore full capacities and self-scouring velocities

- To prevent destruction of pipe

- To prepare for rehabilitation procedures such as slip-lining, mortar lining and internal grouting

- Reduction of septic conditions and hydrogen sulfide generation can increase life expectancy for the pipe line.

Root control is a significant sewer maintenance function. Municipalities frequently have rodding machines engaged in unstopping root blockages, often on an emergency rather than a preventive maintenance basis. Thorough root removal is a requirement of adequate cleaning in preparation for internal pipe inspection and rehabilitation.

Background Information

Roots grow toward moisture by a continuous process (hydrotropism) occurring at the very end of the root. One cell at a time is added at the end of the root enabling it to penetrate extremely small openings in the pursuit of moisture. Sewer pipes which are always below the groundwater level do not have root intrusion because roots do not need to enter the pipe to find water vapor. Tree roots are not hydrophylic and rarely enter a sewer pipe below the water level within the pipe. They most often enter shallow pipes which are above groundwater, or pipes which are seasonally above the groundwater table.

The ends of roots are composed of tender primary tissue. As a root grows longer and larger, living tissue (phloem) exists near the surface. Under the phloem is a thin formative layer(cambium) that gives rise to new cells and is responsible for secondary growth. The center portion of a root (xylem) constitutes the woody element which becomes stronger as the root grows larger. When a root enters a sewer pipe joint, above the water line, it is likely to grow larger on both sides of the hole through which it came until the hole is effectively sealed. The woody xylem contains parenchyma cells which are capable of dividing even when mature and may eventually exert sufficient force to break the pipe.

After a root enters sewer pipe, it may divide hundreds of times to form an enormous mass of tender root ends. The root mass usually collects a thick coating of grease, becomes heavy and hangs into the water causing grit settlement and shoaling. Debris and sewage solids continue to pile up on the root mass until a blockage occurs.

A typical emergency response to a sewer line blockage is to rod the line using an auger tool. The blockage will be relieved and a clump of roots is likely to be pulled out of the line. Unfortunately, much of the root mass will probably remain. The remaining roots respond to their injuries by producing traumatic acid in order to hasten and thicken their regrowth.

In low water table areas, trees such as camphor and willow can produce shallow distant roots reaching 30 feet beyond their branches.

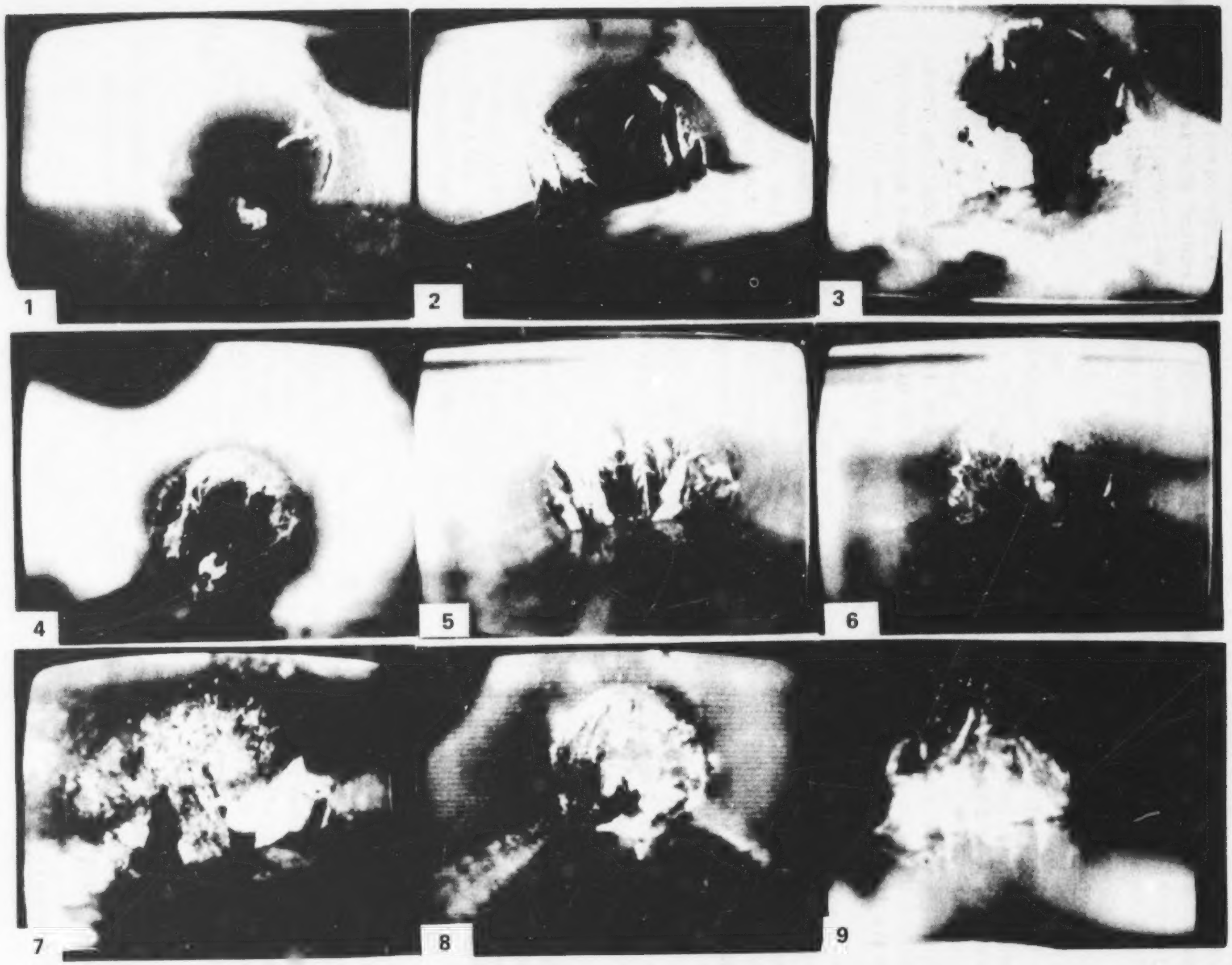
Prevention

Pipes constructed with watertight durable joints are unlikely to have root intrusion. Unfortunately, less emphasis is placed on the tightness of pipe joints when the pipe is above the groundwater level than when infiltration would occur.

Effectiveness of Root Control: The effectiveness of root control procedures has been evaluated on the basis of how often control measures were required to prevent line stoppage. The general location of the roots can be determined when mechanical tools are used, but not whether or not the roots are from a joint or house lateral.

An evaluational root control procedure utilizing internal inspection (TV) can provide guidance for the development of a comprehensive program. Each joint with roots should be identified and the amount of root growth at the joint classified. Root growth should be rated from one to nine with ten representing a complete screen of roots.

The camera operator should be furnished with a set of photos representing varations in root growth. Figure 6 is such a training tool developed by the Sacramento County Department of Public Works.



Source: Sacramento County, California, Department of Public Works

Figure 6. Representative variations in root growth.

Root control programs are not a permanent, one time operation. The conditions which allow a root to enter the pipe are not changed by the root control program. Thus roots may continue to grow or new roots intrude. Use of the visual evaluation technique on control sections of the sewer system allows decisions as to cost-effectiveness of removal technique and the frequency with which maintenance operations should be repeated.

1. Mechanical Removal

When root blockages occur, mechanical removal provides the only immediate relief. Mechanical removal is usually performed by rodding machines, bucket machines, or hard winches using a variety of end tools such as augers, root saws, buckets, scrapers, porcupines, brushes and squeegees. High velocity jet machines can use special root cutting tools although their applicability is generally limited to moderate root growth in 8, 10, and 12 in. (20, 25, and 30 cm) pipes.

Partial root removal encourages regrowth. If, however, the roots are completely removed and cut off flush at the pipe wall, a considerable length of time will be required for regrowth. Woody root xylem will fill up much of the hole through which the root originally came. New growth must come from the relatively thin cambium surrounding the xylem.

Full gauge cleaning tools are required for complete root removal, however, they cannot always be used due to the presence of intruding service connections and badly offset joints.

Mechanical cleaning of roots generally leaves a part of the root intact hastening regrowth. Television inspection following cleaning by a variety of root cutting tools has shown this to be a general case. The presence of roots extending out into pipe from the joint is particularly a problem if the urethane foam grout is to be used as the grout will adhere to the root and possibly obstruct flow or hinder future cleaning operations.

2. Copper Sulfate

An early method for chemical control of roots in sewer lines was to place several pounds of copper sulfate periodically in manholes upstream of troubled sections. This method of root treatment allows no control over concentration of poison or duration of exposure. Tests by Ahrens, Leonard, and Townley (2) using very high concentrations of copper sulfate (10,000 mg/1) for one hour caused systemic injury without completely killing roots.

Unfortunately, copper absorbed by roots killed with copper sulfate is also poisonous to bacteria and fungi which would normally decompose the dead roots.

3. Herbicides

A comprehensive study of numerous herbicides was made by Ahrens, Leonard, and Townley (2). Herbicides tested in their root control experiments are given in Table 2.

In the screening tests, roots not only were consistently killed with dichlobenil at 100 mg/l, but also regrowth above the point of treatment was inhibited. Because of its known safety and use as an aquatic herbicide and its toxicity to roots at low concentrations, dichlobenil seemed to be a good candidate herbicide for further studies. (2)

A combination of metham at 500 mg/l and dichlobenil at 10 mg/l completely killed eucalyptus roots with negligible foliage injury. These results formed the basis for more intensive study with metham and dichlobenil to determine the importance of factors that might affect root kill and systemic movement of metham to foliage. (2)

Experiments in sewer lines showed that flood treatment with dichlobenil and metham can effectively kill tree roots. Dichlobenil is an effective inhibitor of root growth even at sublethal concentrations, and metham has the ability to kill roots for a distance above the point of contact. In combination, they achieve immediate root kill and a deterrent to regrowth.

Flood treatment permits control of herbicide concentration and contact time during application. The chief advantage of flood treatment over spraying or foaming is that it assured penetration of root-infested joints and may allow some exfiltration and killing of roots outside the pipe.

Extensive field testing of dichlobenil and metham has been performed by the County of Sacramento and is reported by Townley(3). Pursuant to preliminary tests, large scale field applications were undertaken using a concentration of roughly 3,000 mg/l metham and 200 mg/l dichlobenil plus wetting agent. It should be noted that the water solubility of dichlobenil is low (about 18 mg/l). The use of 200 mg/l merely assures that the treating solution is saturated with dichlobenil.

In part, Townley concludes:

> "Our field applications have provided excellent results. A root kill of at least 50 percent is the normal minimun. Our average kill is about 75 percent. To achieve these results careful attention must be given to application procedures. Chemical concentration and contact time are absolutely essential to effective treatment. Careless application can only result in unsatisfactory results. These herbicides cannot be effectively applied by simple flushing down a commode or simple pouring into sewage flow from an available manhole. The chemical must be thoroughly mixed with the solution water and held in positive contact with root growth for one hour."

TABLE 2. CHEMICALS TESTED FOR ROOT CONTROL

COMMON NAME	CHEMICAL NAME	TRADE NAME	FORMULATION
Bensulide	0,0-diisopropyl phosphorodithioate S-ester with N-(2-mercapto-ethyl) = benzenesulfonamide	Prefar	Emulsifiable concentrate
Dichlobenil	2,6-dichlorobenzonitrile	--	1% emulsion
		Casoron W50	50% wettable powder
Dinoseb	2-sec-butyl-4,6-dinitrophenol	Premerge	Alkanolamine salt
Endothall	7-oxabicyclo (2.2.1) = heptane-2,3-dicarboxylic acid	Dipotassium endothal	Dipotassium salt
		Hydrothol 191	Cocoamine salt
Metham (SMDC)	sodium methyl = dithiocarbamate	Vapam	Water soluble concentrate
		Vaporooter	Vapam + surfactant
Paraquat	1,1'-dimethyl-4,4'-bipyridinium-ion	Paraquat	Water soluble concentrate
Trifluralin	a,a,a, trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine	Treflan	Emulsifiable concentrate
2,4-D	(2,4-dichlorophenoxy) acetic acid	Dow Formula 40	Alkanolamine Salts
		Weedone LV4	Butoxyethanol-ester
2,4,5-T	(2,4,5-trichloro = phenoxy) acetic acid	Weedar 2,4,5-T	Triethylamine salt
Copper sulfate	copper sulfate $5H_2O$	Bluestone	94.3% pentahydrate
Chlorthiamid	2,6-dichlorothiobenzamide	Prefix	7.5% granules

Flooding cannot be used in many areas due to topography. During the past year, several local authorities have successfully utilized the herbicide in the form of foam. When applied to a sewer, a plastic hose is inserted to about the center of the reach and then retrieved, filling the pipe with foam. Others have foamed the entire line, not retrieving the line until foam appears at the downstream manhole.

Action of the sewage in the line appears to keep the foam at the top and sides of the pipe where it can come in contact with roots.

Foam can also be used to treat house connections. Entrance to the property is blocked and then the foam is allowed to fill the sewer connection.

Cleaning to Remove Roots: After a period of six to twenty weeks, the roots in the sewer will either fall off or break at the sewer wall when a rod or hydraulic cleaner is used. New or regrowth appears to be minimized.

Chemical Grout and Admixtures: The toxicity of acrylamide grout, acrylamide grout fortified with metham, and acrylamide grout fortified with dichlobenil was evaluated by Ahrens (4):

> "Metham increased the gel time, requiring a higher concentration of catalyst, but dichlobenil did not effect gel time. The standard gel killed most of the treated apple root sections whereas the fortified gels killed all treated root sections. Roots were killed further above the treated section with metham or dichlobenil than with standard grouting materials. In time, branch roots developed normally above root sections killed with all gels. Willow roots penetrated sand gels formed by the standard or metham fortified grouting materials but did not penetrate the gels fortified with dichlobenil."

Formulations of the root control chemicals with a USEPA approval number are marketed by the Airrigation Engineering Company, Inc., Carmel Valley, California.

Acrylamide grout containing dichlobenil is available as AM-9 plus. Urethane grout containing a root growth inhibitor in the formulation is also available.

4. Scalding Water Flooding

Scalding water will kill tree roots regardless of transpiration rate, without damage to foliage or ill effects on treatment processes (5).

Enzymes start to lose their catalytic properties at 95° F (35° C) and are completely denatured at 140° F (60° C). Denaturation by temperature is more general and efficient (than poison) because it is able to break those disulfide bonds which are deeply buried within the protein molecule and shielded from heavy metal attack. Once denaturation has taken place it is almost always irreversible. A temperature of 122° F (50° C) will kill most plant tissue; 140° F (60° C) will kill almost all living tissue. Somewhat higher temperatures will break down root cell walls of the phloem causing physical damage and accelerated decomposition by attack from bacteria and fungus. Contact time depends upon the diameter of the root, i.e. time to heat the root.

Penetryn has reported that a full scale test using a three million BTU/hr boiler (private correspondence received from Penetryn, May, 1975) was able to maintain the proper temperature by controlling the release rate of the impounded water. Cost-effectiveness data are not yet available.

COST DATA DEVELOPMENT

Cleaning Costs

It is important for the investigator of sewer system infiltration/inflow conditions to recognize those factors which will most affect the cleaning of sewer lines if a true understanding of the subject problem is to be achieved. Although these factors are rather complex and interrelated, they can generally be divided into two basic categories: (1) sewer cleaning difficulty factors; and (2) labor cost factors.

As the task of cleaning sewer lines is labor-intensive, representing between 25 and 35 percent of the daily operating cost; the cost, productivity, availability and restrictions of the labor force is a signficant determining factor in the ultimate cost for performing sewer cleaning tasks.

Therefore, equivalent work in major metropolitan areas will undoubtedly be more costly than work in a rural area. Likewise, cleaning of sewer lines in the northern areas will generally be more costly than work performed in the southern portions of the United States.

Of equal, if not greater, importance to the cost of sewer cleaning is an understanding of cleaning difficulty factors. These factors will determine the selection of equipment to be used, the size of the cleaning crew required, and the rates of productivity which can be achieved. They all affect the total cost.

Some of the significant factors associated with sewer cleaning are shown in Table 3.

To demonstrate the effects of varying difficulty factors, as they relate to overall sewer cleaning cost, two examples of performing a single basic task are presented.

From the examples the effects of change in difficulty factors can easily be seen. In Example 1, where both manholes are easily accessible by large trucks and water is available at the site, a jet cleaner could be used, requiring only a three-man crew with an anticipated productivity rate of 700 ft (213 m) per day. However, in Example 2, where neither manhole access nor water is available, the bucket machine cleaning process was selected, requiring a four-man crew with an anticipated production rate of only 300 ft (91 m) per day.

TABLE 3. SEWER CLEANING DIFFICULTY/COST FACTORS

Access to Manholes	Length of Manhole Section
Condition of Manholes	Intruding Building Sewers
Type of Manhole Construction	Requirement for Transportation and Disposal of Material Removed from the Sewer
Size of Manholes	Distance to Disposal Site
Depth of Sewer Lines	Traffic Control Required
Depth of Flow In Sewer	Availability of Water
Type of Deposition in Sewer	Degree of Root Intrusion
Size of Sewer to be Cleaned	Successive Manhole Section versus Random Section Cleaning
Structural Condition of Sewer to be Cleaned	Weather Conditions

EXAMPLES 1 AND 2

Definition of Task

Clean 8 in. (20 cm) diameter sanitary sewer line

Type of pipe - clay
Amount of debris - 1/3 full, or 2.7 in. (6.5 cm)
Type of debris - heavy sand
Length of manhole section - 300 ft (91 m)
Depth of line - 6 ft (1.8 m)
Amount of flow - 20 percent of capacity

Factor	Example 1	Example 2
a) Traffic Control	- Not required	- Not required
b) Access Manholes	- Both manholes available	- Minimum access
c) Water	- Available at site	- Not required
Selection of Equipment	- Jet cleaner	- Bucket machines
Crew Size Required	- Three men	- Four men
Production Rate/day	- 700 ft (213 m)	- 300 ft (91 m)

As can be seen, broad-based differences can be incurred in the cost of sewer cleaning depending on many varying and interrelated factors, such as access. The difficulty factor differences between cleaning sewers located under streets versus cleaning sewers located in ravines with no vehicular access are extreme. In order to develop an accurate estimate of expected cleaning cost, each element (cleaning difficulty factors - labor costs) should be identified, defined, and assessed with respect to its influence on the selection of equipment, crew size required, and anticipated productivity accomplishments. Once the specific area of work has been selected, such as the particular manhole sections, then qualified sewer cleaning contractors may be contacted to assist in the assessment of the difficulty factors and provide experienced judgement regarding equipment selection, anticipated productivity rates and probable cost ranges.

Figure 7 gives cost data based on specific assumptions and the change relationship which occurs with changing difficulty factors or changing labor cost factors. The assumptions established for the example, as identified in Figure 7 are as follows:

Access to Manholes	- Both manholes are located in paved streets and readily accessible to all types of cleaning equipment.
Condition of Manholes	- Both manholes are structurally sound and have steps for personnel access.
Type of Manhole Construction	- Manholes are constructed with precast concrete.
Size of Manholes	- Manholes are 4 ft (1.2 m) diameter, with minimum opening through the manhole cover frame of 21 in. (53 cm).
Depth of Sewer Line	- Average 6 ft (1.8 m) depth.
Depth of Flow in Sewer	- 20 percent of pipe diameter.
Depth of Deposition in Sewer	- 25 percent of pipe diameter.
Size of Sewer to be Cleaned	- 6 in. (15 cm) through 36 in. (91 cm).
Length of Manhole Section	- 350 ft (107 m)
Requirements for Transportation and Disposal of Materials Removed from the Sewer	- Disposal area is approximately 3 mi (5 km) from the work site and accessible via non-congested paved roadway.
Traffic Control	- No barricades or uniformed traffic control are required. - Flashing beacons on vehicles are sufficient.
Availability of Water	- Water is available from fire hydrants throughout the work area.
Degree of Root Intrusion	- None.
Successive Manhole Sections	- All cleaning required is in successive manhole sections.

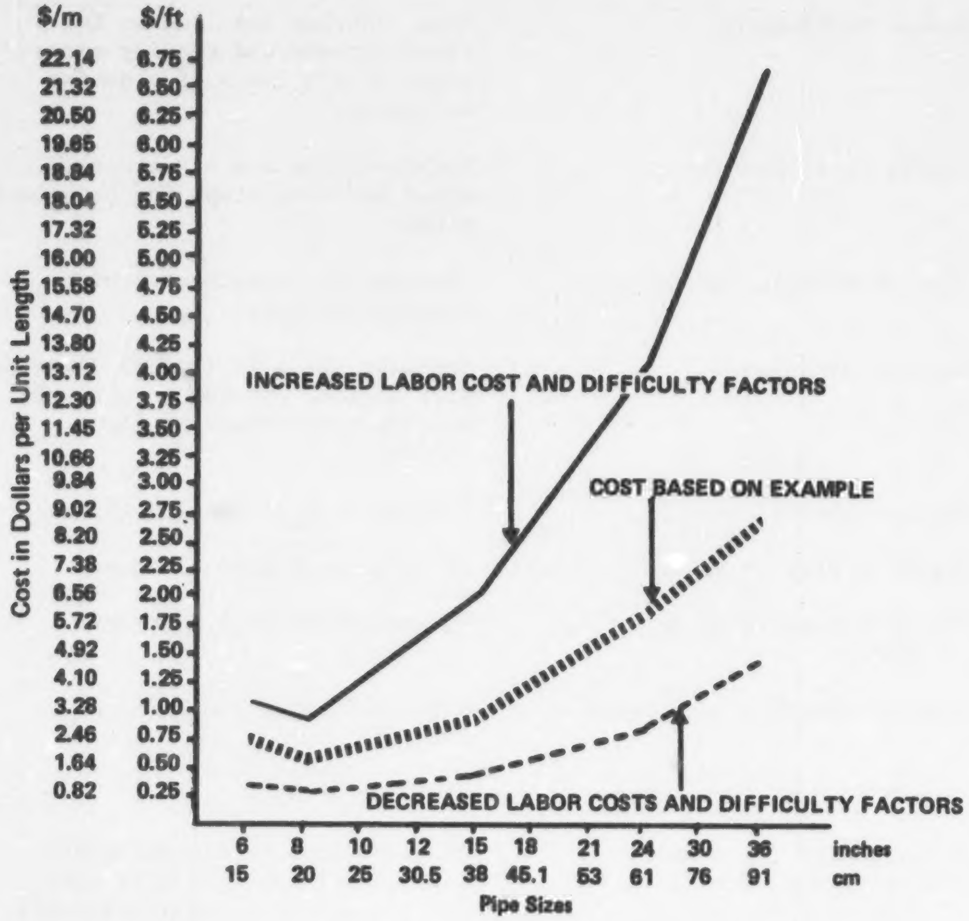


Figure 7. Basic cleaning cost data.

Inspection

For the purpose of this section, references to internal pipe inspection, pipe inspection or inspection include closed-circuit television or photographic procedures. Though the methods and results are different, the costs of the two procedures are about the same.

As with sewer cleaning, internal pipe inspection is a labor-intensive task. Material costs, such as photographic film and video tape are small in comparison to cost of supervision, technician services and labor. Therefore, labor availability, skill availability, productivity of the labor force and labor cost have a significant influence on total inspection costs.

Significant inspection factors are shown in Table 4. Such factors influence the cost of inspection due to crew size, crew skill requirements, productivity rates or need for special or auxiliary equipment.

TABLE 4. INSPECTION DIFFICULTY/COST FACTORS	
Length of Manhole Section	By-pass Requirements
Access to Manholes	Pipe Size
Terrain	Pipe Cleanliness
Traffic Control Requirements	Presence of Combustibles
Manhole Conditions	Pipe Structural Conditions
Depth of Sewer Line	Weather
Depth of Flow	Random vs. Successive Sections
Flow Rate	Documentation Requirements
Flooding Conditions	Report Requirement
Plugging Requirements	

Another element and/or requirement that will have a major impact on cost of the inspection task is the nature of the reporting requirement. In some instances, filing of bound copies of the field report and field recordings is sufficient; in other cases a complete engineering report, including voluminous information not ordinarily collected during the inspection task, is required and extensive analyses of this information must be furnished. These requirements would not only increase the cost, but would also increase the technical skills required to perform the inspection and require expensive engineering capability in the field during the performance of the task.

In determining what costs might be involved in an inspection project, each of the factors discussed should be considered and assessed as to their probable impact. In addition, a well defined objective with required results should also be indicated. Assistance in developing expected cost data may also be sought from one of the many reputable inspection firms around the country.

Basic inspection costs are presented in Figure 8, which provides ranges reflecting the most common combinations of difficulty factors, labor cost and technical/report requirements. The "example cost" shown is based on the criteria established by the following example using 1974 average labor costs.

EXAMPLE 3

a) General Requirements--

Inspect a system for physical integrity and condition prior to a street paving program. Typed copies of the field inspection log sheets, accompanied by a minimum number of photographs showing representative findings, constitutes the report requirements. No engineering analysis,

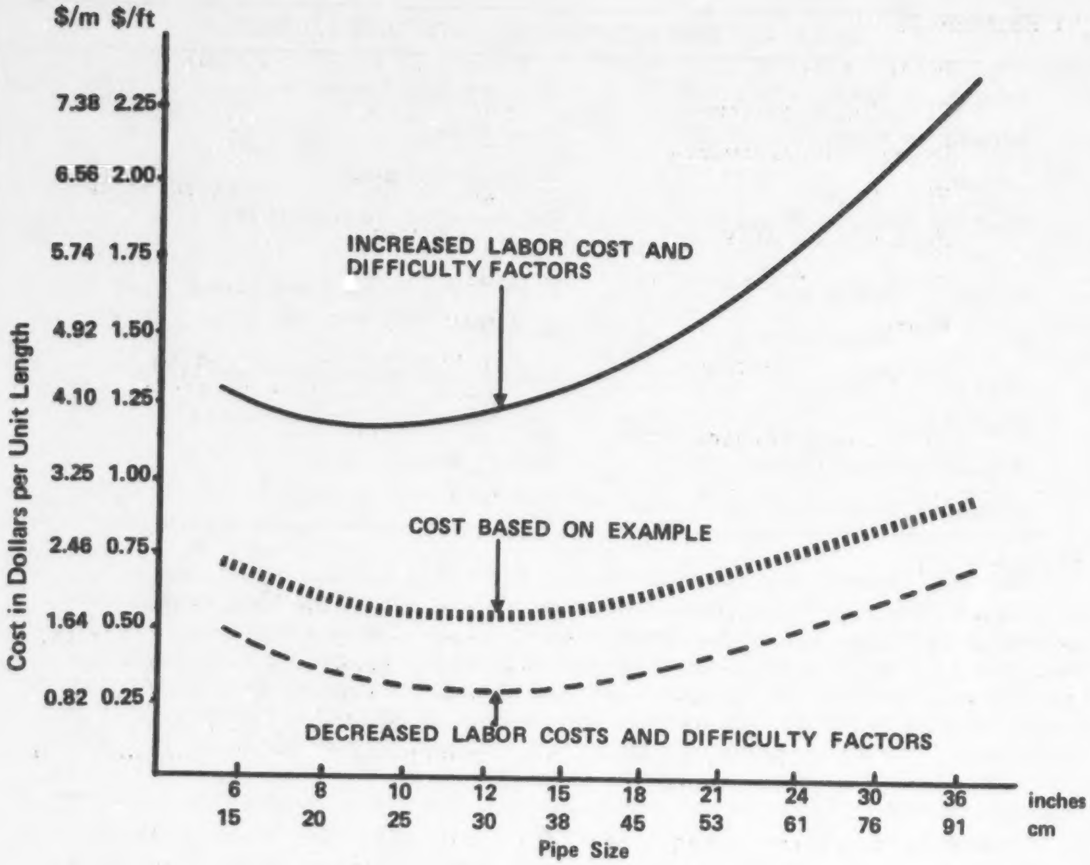


Figure 8. Internal pipe inspection cost data.

flooding of storm sewers during the inspection, or other auxiliary activities are necessary.

b) Specific Site Conditions--

Mobilization Distance	- 10 mi (16.1 km)
Length of Manhole Section	- 375 linear ft (114 m)
Manhole Location	- Both manholes are located in paved streets and readily accessible to all required equipment.
Traffic Control	- None required.
Manhole Conditions	- Both manholes are structurally sound and have steps for personnel access.
Depth of Flow	- Less than 20 percent of pipe diameter.

[b) continued]

Depth of Sewer Line	- 6 to 8 ft (1.8 to 2.4 m)
Plugging Requirements	- None
By-pass Requirements	- None
Pipe Size	- 6 in. to 36 in. (15 cm to 91 cm)
Pipe Cleanliness	- Satisfactory
Presence of Combustibles	- None
Weather	- Summer day with no rain
Successive Sections	- All inspection required is in successive manhole sections.
Protruding Service Taps	- None anticipated

COST DATA DEVELOPMENT - (Sanitary Sewers Only)

Smoke Testing

Smoke testing is primarily used to detect points of inflow during favorable groundwater and weather conditions. Although seemingly simple, smoke testing should be performed by experienced people who are aware of what it does not reveal as well as what it does. Effectiveness of smoke tests is dependent on thorough documentation of findings, including description of smoke leaks, numbered photographs and maps showing locations of leaks with adequate measurements.

Smoke test equipment requirements are minimal. Costs are relatively unaffected by pipe size except for an exponential increase in smoke consumption in larger pipes. Unit costs are mostly sensitive to location, such as downtown vs. residential areas and number of leak points detected and documented.

The following unit costs are for performing smoke testing and supplying copies of field reports. These costs are exclusive of the required public relations efforts, including notification of fire departments and homeowners and handling complaints. The costs do not include detailed analysis and specific recommendations for remedial action.

Sanitary Sewer Smoke Testing Cost Data

Pipe Size	Cost Per Foot	Cost Per Meter
6-15 in. (15-38 cm)	\$ 0.15 to \$ 0.25	\$ 0.49 - \$ 0.82
18-36 in. (46-91 cm)	\$ 0.20 to \$ 0.30	\$ 0.65 - \$ 0.98

Note: The above costs are based on 1974 labor and material costs, and would not necessarily include a complete engineering analysis report.

Manhole Rehabilitation Costs

Manhole rehabilitation cost estimates require an understanding and evaluation of numerous interrelated factors. These include type of manhole construction; type, cause, and extent of failures; depth of manhole; type of soil surrounding the manhole; manhole location; selection of the rehabilitation techniques; selection of rehabilitation materials, etc. A list of possible manhole rehabilitation techniques is provided.

Rehabilitation Techniques:

Internal Cement Grouting by Pressure Injection
Internal Chemical Sealant Grouting by Pressure Injection
External Chemical Sealant Grouting by Soil Injection
External Cement Grouting by Soil Injection
Internal Epoxy Mortar Resurfacing
Internal Cement Mortar Resurfacing or Guniting
Mortar Joint Replacement by Pressure Injection
"External Drop" Sealing
Resetting and Resealing of Manhole Frames

Each of the above techniques may be utilized separately or combined in various manners depending on manhole condition and the extent, type and nature of rehabilitation required. The obvious difficulty is in determining which technique or combination of techniques will be required. The selection is generally dictated by type of manhole construction in conjunction with the nature of the physical failure involved.

EXAMPLE 4

A) Basic Problem:

Manhole is structurally sound. The corbel section and base are in good condition. Infiltration through the walls is significant.

B) Type of Manhole Construction:

Manhole A	Manhole B
Precast Base	Precast Base
Precast Walls	Brick and Mortar Walls
Brick and Plaster Corbel	Brick and Mortar Corbel
48 in. (1.2 m) Diameter	48 in. (1.2 m) Diameter

C) Selection of Rehabilitation Technique:

Manhole A - Infiltration can be contained within the small area between segments, therefore, internal chemical grouting or sealing would be selected for use because of:

- Ease of developing entry into the leakage source
- Minimum quantities of chemical grouting materials required
- Minimum risks of renewed infiltration in other areas of the manhole
- Work accomplished at one time with a single crew and set-up.

Manhole B - The leakage will not be well defined and cannot be contained within a small wall section area. Its entry is through the mortar joints. The sealing of the obvious points of infiltration would merely divert the flow of water to other weak mortar joints where it would again enter the manhole. With these conditions prevalent a combination of three techniques would be selected: Mortar joint replacement by pressure injection; internal epoxy or cement resurfacing; and internal chemical grouting. With the above technique selected, timing would become critical because the first two procedures should be carried out during "dry" conditions, while the last would be done during periods of maximum groundwater levels.

As the example indicates, the cost of manhole restoration is dependent upon type of manhole construction; nature and extent of the failure; and type of rehabilitation technique or combination of techniques required to effect the proper repair.

Table 5 provides basic understanding of the rehabilitation task cost impacts. It is not the intent of this presentation to establish cost ranges for estimating purposes. Unlike other activities discussed in this section, manhole rehabilitation costs are comprised of almost equal proportions of labor costs and material costs. Therefore, material selections and material costs markedly affect the total cost and make it impossible to establish fixed and/or predictable cost ranges.

The cost data, as shown in Table 5 are based on 1974 real cost data for labor, supervision, materials, and the following set of basic example criteria:

Access - Manhole located in paved street
Depth of Manhole - 6 ft (1.8 m) to 8 ft (2.4 m)
Diameter of MH - 4 ft (1.2 m)
Depth of Flow - 20 to 25 percent of pipe diameter
Combustible Gases - None present

Sewer Line Grouting

The cost information presented covers only internally applied chemical grouts, either Acrylamide Gel or Urethane Foam Grout. Though there are other techniques and materials which have been used over the years for sewer line grouting, little is known of either their successes

TABLE 5. BASIC MANHOLE REHABILITATION TASKS AND COST RELATIONSHIP

Basic Rehabilitation Task	TYPE OF MANHOLE CONSTRUCTION				Minimum Cost Range
	Brick and Mortar	Brick and Mortar w/ Plaster	Concrete Block and Mortar	Pre-Cast or Cast in Place	
Reset and Seal Manhole Frame	X	X	X	X	$100.00–$150.00
Chemical Grouting – Base Only	X	X	X	X	$ 75.00–$125.00
Chemical Grouting – Walls Only				X	$150.00–$125.00
Plaster and Seal Walls	X	X	X		$180.00–$197.00/vertical meter ($ 55.00–$ 60.00/vertical foot)
Joint Replacement w/ Pressure Injection	X		X		$131.00–$164.00/vertical meter ($ 40.00–$ 50.00/vertical foot)
Cement Grouting – Base Only	X	X	X	X	$150.00–$175.00
Cement Grouting – Walls Only	X	X	X	X	$250.00–$500.00
Chemically Grout External "Drops"	X	X	X	X	$150.00–$250.00

Note: The success in manhole rehabilitation depends on –

1. Verifying that the manhole condition and environment allows rehabilitation
2. If grouting is being considered – that the soil is groutable
3. That the proper selection of rehabilitation techniques is made and that the tasks are performed in proper sequence.

or relative costs. As described in this section, the techniques for applying the two sealants are similar as are the requirements for personnel and equipment. This makes the cost, other than for material, comparable. The material costs vary considerably, with Urethane Foam Grout costing approximately twenty times that of Acrylamide Gel in equal quantities. In application, however, these costs become almost equal due to the smaller quantities of the former material required.

The operating costs of internal sewer line grouting are comprised of two major elements: (1) Labor and supervision; and (2) the grouting materials (base chemical components plus additives), with the materials representing between 15 and 25 percent of the total operating costs. Therefore, not only do the factors shown in Table 6 affect costs but the material cost, transportation cost, and quantities of materials required also have significant impact on the total costs. The difficulty factors dictate the crew sizes, equipment and rate of productivity in the grouting operations.

In order to present some relative cost data, certain basic exclusions were made in the example calculations shown in Figures 9 through 13.

a) No cost calculations are included for any by-passing of sewage flow around the manhole section during the grouting operation.

TABLE 6. SEWER LINE GROUTING DIFFICULTY/COST FACTORS

Mobilization Distance
Weather Conditions
Access to Manholes
Terrain
Type of Soil
Manhole Opening
Manhole Size
Manhole Cleanliness
Manhole Depth
Type of Pipe
Pipe Alignment
Pipe Grade
Pipe Cleanliness
Depth of Flow
Flow Rate
Ability to Plug
Hazardous Gas
Type of Joint
Joint Spacing
Offset Joints
Protruding Service Connections
Structurally Damaged Pipe
Random vs. Successive Manhole Sections

b) No provisions or allowances are made for any sewer cleaning. (Cost of this task is portrayed in a previous portion of this Section.)

c) No provisions or allowances are made for any pre-inspection of the individual line sections to be grouted. (Cost of this task covered in a previous part of this Section.)

d) No provisions or allowances are made for any soil tests, analysis, etc., necessary to substantiate that the soil is groutable.

e) No provisions or allowances are made for any other investigative work required to pre-establish the probability of a successful grouting application.

To further establish some base line criteria for cost calculation purposes, Example 5 was developed and is used in Figures 9 through 13 to indicate what the cost might be as compared to a minimum and maximum cost based upon the number of joints grouted per setup, by diameter of pipe.

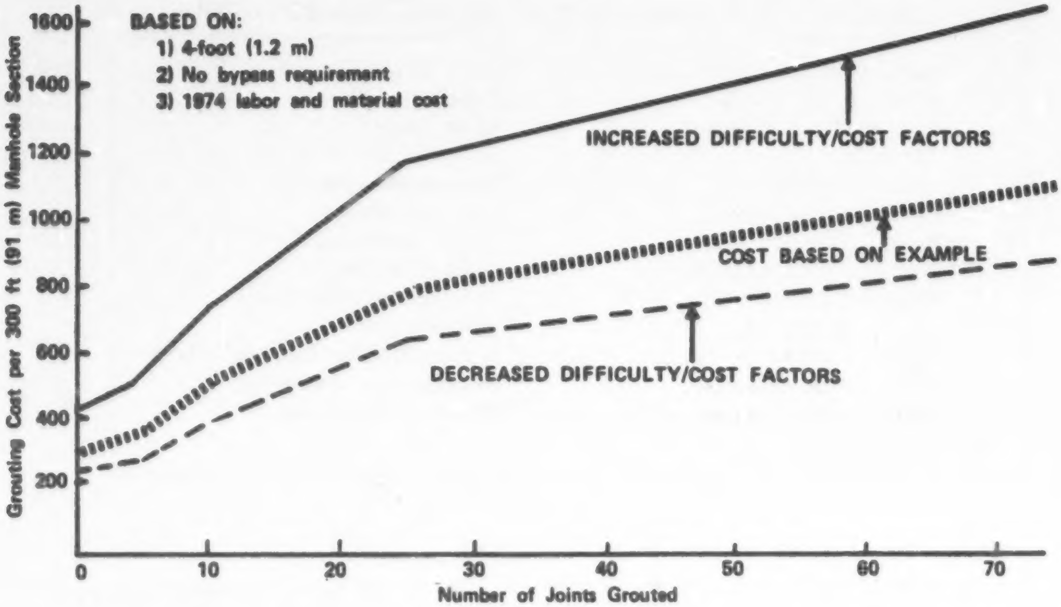


Figure 9. Grouting cost per 300 ft (91 m) manhole section – 8-12 inches (20-30 cm) pipe versus number of joints grouted.

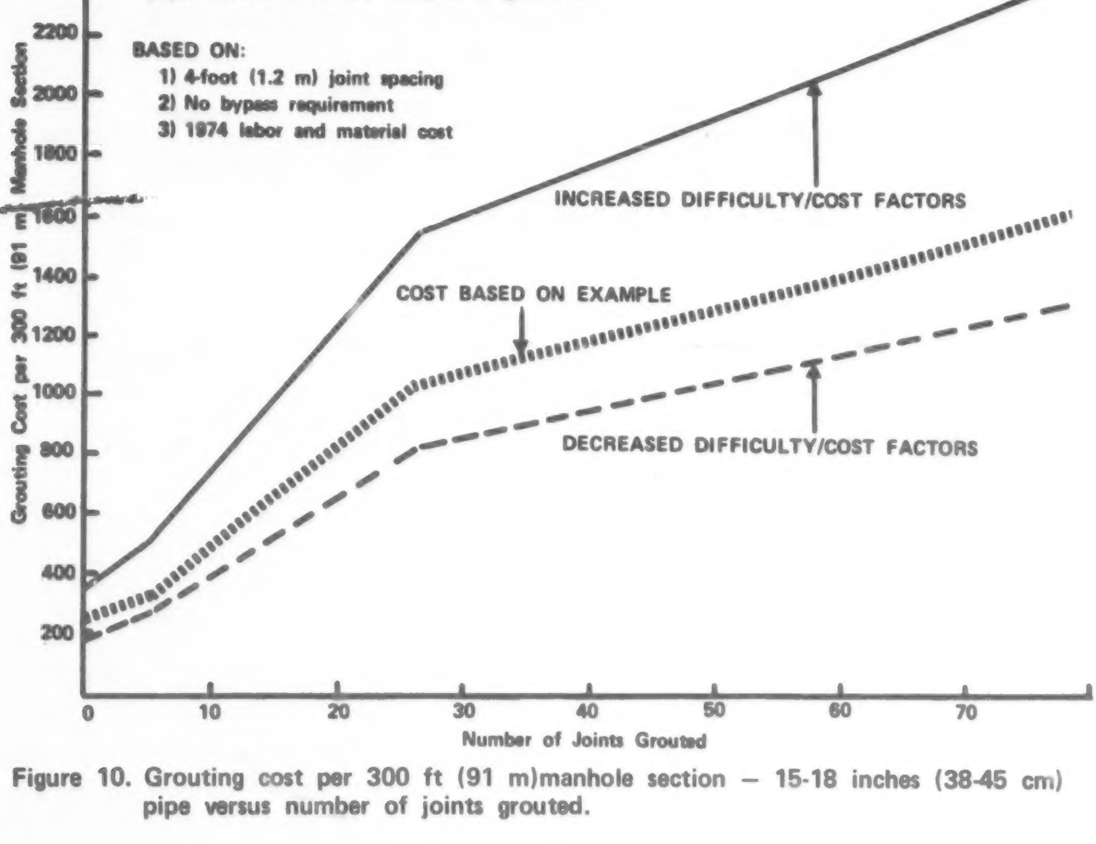


Figure 10. Grouting cost per 300 ft (91 m)manhole section – 15-18 inches (38-45 cm) pipe versus number of joints grouted.

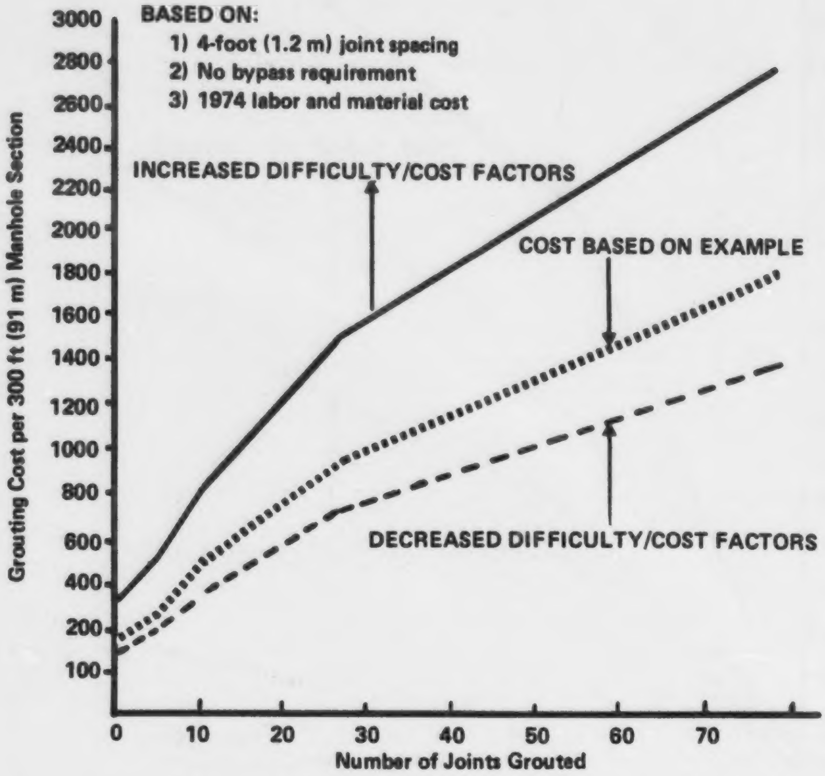


Figure 11. Grouting cost per 300 ft (91 m) manhole section – 6 in. (15 cm) pipe versus number of joints grouted.

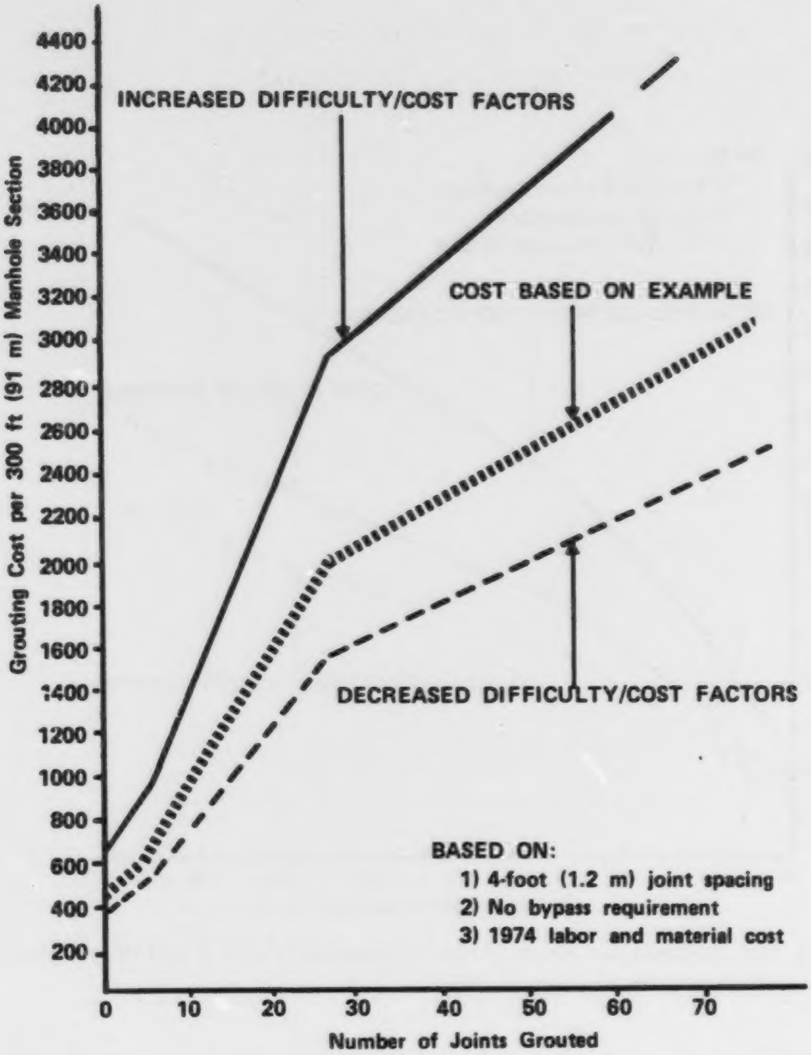


Figure 12. Grouting cost per 300 ft (91 m) manhole section – 21-24 inches (53-61 cm) pipe versus number of joints grouted.

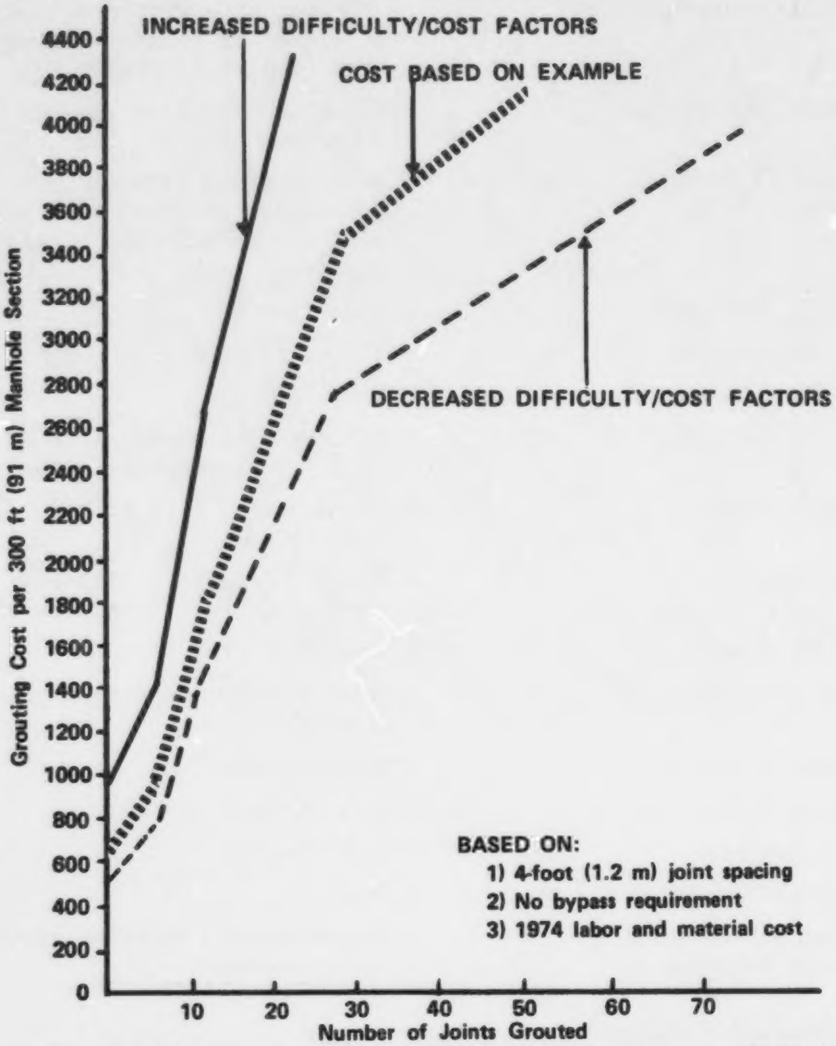


Figure 13. Grouting cost per 300 ft (91 m) manhole section – 30-36 inches (76-91 cm) pipe versus number of joints grouted.

EXAMPLE 5

Cost of Grouting

Difficulty/Cost Factor	Condition
Mobilization Distance	- Project site within 100 mi (161 km) of company office and shop facilities
Weather Conditions	- Mild temperatures; absence of storms
Access to Manholes	- Both manholes readily accessible by paved road and will accommodate the necessary equipment
Traffic Control	- None required
Manhole Opening	- 21 in. (53 cm)
Manhole Diameter	- 4 ft (1.2 m)
Manhole Condition	- Structurally sound, with steps for personnel access
Manhole Depths	- Between 6 ft (1.8 m) and 8 ft (2.4 m)
Pipe Size	- Ranging from 6 in. (15 cm) through 36 in. (91 cm) in diameter
Type of Pipe	- Vitrified clay
Depth of Flow	- Less than 20 percent of pipe diameter
Hazardous Gas	- None present
Type of Joint	- Factory made
Joint Spacing	- 4 ft (1.2 m)
Structurally Damaged Pipe	- None
Random vs. Successive Manhole Sections	- All sections requiring grouting are successive

Pipe Lining (Polyethylene)

The costs of rehabilitating sewer lines by insertion of polyethylene liner pipe will vary greatly due to the large number of variables and difficulty factors which may be encountered. These factors are shown in Tables 7 and 8.

TABLE 7. PIPE LINING COST VARIABLES

- Liner pipe wall thickness required
- Annulus grouting requirements
- Number of service connections to be made
- Size of pipe to be lined
- Type of surface restoration required
- Pipe transportation requirements
- Type of manhole "seals" needed
- Length of sewer to be lined
- Availability and cost of labor
- Extent of sewer cleaning required
- The technique to "prove" or pre-inspect the sewer line

TABLE 8. PIPE LINING DIFFICULTY/COST FACTORS

- Mobilization distance
- Size of liner pipe to be handled
- Depth of sewer to be lined
- Excavation requirements
- Groundwater elevation
- Grade and direction change of the sewer to be lined
- Depth of flow in the sewer line
- Lining Costs
- Access to the site of work
- Availability of electrical power for fusing
- Storage area at the site for pipe materials
- Storage area at the site for excavated materials

Each of these factors, independently or in combination, can have a major impact on the overall cost of a lining project. A thorough understanding of each of these factors on an individual project basis is required before a realistic cost estimate can be made. Table 9 is presented as an illustration of a typical "Estimating Guide." It identifies the cost elements by sequence of task that can be segregated for cost determination purposes.

Each lining project is sufficiently different in its complexities, combinations of difficulty factors, and variables to make the presentation of any general total cost information impossible. It is the intent of this section to provide the reader with a general understanding of the various factors that may effect the cost of a project (Tables 7 and 8) and the elements that must be considered when developing a cost estimate.

TABLE 9. TYPICAL ESTIMATING GUIDE (COST ELEMENTS)

A. PREPARATION
   1. Sewer Line Cleaning
   2. TV Inspection
   3. "Proving" of Sewer Line

B. COST OF PIPE
   1. Diameter of Existing Sewer
   2. Diameter of Liner Pipe
   3. Depth of Sewer Line
   4. Wall Thickness and Strength Required
   5. Length of Pipe Required
   6. Cost per lb (kg)
   7. Weight Required
   8. Freight to the Site

C. INSERTION PITS
   1. Depth of Pit
   2. Equipment Required
   3. Crew Size Required
   4. Crew Cost
   5. Time Required
   6. Special Conditions
      a) Shoring Required
      b) De-Watering Required
   7. Cement for Curing Liner Pit
   8. Paving Required
   9. Manhole Repairs

D. WELDING PIPE
   1. Crew Size Required
   2. Crew Rate
   3. Number of Welds per Day
   4. Equipment Required - Handling and Fusion
   5. Power Requirements

TABLE 9. (continued)

E. INSTALLING PIPE

1. Winch Equipment Required
2. Pipe Handling Equipment Required
3. Guide Pulleys Required
4. Cable

F. OTHER CONSIDERATIONS

1. Sewage By-Passing Requirements
2. De-Watering Requirements
3. Annulus Grouting Requirements

G. CONNECTING BUILDING SEWERS

1. Type of Connection to be Made
2. Depth of Connection
3. Crew Size Required
4. Crew Rate
5. Number of Connections Made per Day
6. Equipment Required
7. Materials Required
8. Cost of Materials

H. SEALING OFF AT MANHOLES

1. Number of Manholes to Seal
2. Type of Seal Required
3. Cost of Seals
4. Number of Seals Made per Day
5. Crew Size Required
6. Crew Rate

I. TRANSPORTATION

1. Mobilization
2. Demobilization
3. Freight on Materials

Specific cost examples are given and are summarized in Table 10. The examples are intended to demonstrate the wide range of project costs and show the influence of some of the difficulty factors.

TABLE 10. EXAMPLE COST SUMMARY

Cost Element	Situation A 1,000 ft (305 m) 8 in. (20 cm) pipe (concrete) 8 ft (2.4 m) deep	Situation B 1,000 ft (305 m) 8 in. (20 cm) pipe (concrete) 25 ft (7.6 m) deep	Situation C 1,000 ft (305 m) 24 in. (61 cm) pipe (concrete) 25 ft (7.6 m) deep
Preparation	$ 1,000	$ 1,000	$ 2,500
Cost of Pipe	2,000	4,000	35,000
Insertion Pit	6,000	16,000	20,000
Welding Pipe	700	800	3,000
Installation of Pipe	2,500	3,200	6,000
Connect 15 Building Sewers	4,500	9,000	10,000
Sealing off Manholes	1,000	1,500	1,500
Mobilization	300	500	2,000
TOTAL PROJECT COSTS	$18,000	$36,000	$80,000

It is important to remember, as mentioned previously, that each lining project should be cost-evaluated independently, considering all of the specific job requirements, variables and difficulty factors. As illustrated in the Example 6, each project must be costed by the sub-elements involved in order to account for the difficulty factors. The lining cost could vary by over 400 percent depending upon such factors as groundwater depth, depth of pipe, mobilization distance, and size of pipe involved.

EXAMPLE 6 Cost of Pipe Lining

Situation A

Size and Type of Pipe:	8 in. (20 cm) Concrete
Depth of Flow:	20% of Pipe Diameter
Length of Sewer:	1,000 ft (305 m)
Depth of Sewer:	8 ft (2.4 m)
Groundwater Elevation:	3 ft (0.9 m) above Sewer Invert
Soil Type:	Clay
Access to the Site:	Open Field, OK for Vehicles
Pre-Inspection:	Proved Acceptance of Liner
Excavation Requirements:	Single Excavation Adequate
Building Sewer Connection:	15 Connections, Replace to Property Line

Annulus Grouting Requirements: Not Required

Manhole Seals Required: 4 Manholes, 6 Seals

Liner Thickness: SDR(1) 32.5 Wall Thickness

Mobilization Distance: 200 mi (322 km) from Installer

Situation B

Size and Type of Pipe: 8 in. (20 cm) Concrete

Depth of Flow: 20% of Pipe Diameter

Length of Sewer: 1,000 ft (305 m)

Depth of Sewer: 25 ft (7.6 m)

Groundwater Elevation: 17 ft (5.2 m) above Sewer Invert

Soil Type: 0-6 Clay 6-25 Muck and Sand

Access to the Site: Open Field, OK for Vehicles

Pre-Inspection: Proved Acceptance of Liner

Excavation Requirements: Single Excavation Adequate

Building Sewer Connection 15 Connections, Replace to Property Line

Annulus Grouting Requirements: Not Required

Manhole Seals Required: 4 Manholes, 6 Seals

Liner Thickness: SDR 17 Wall Thickness

Mobilization Distance: 200 mi (322 km) from Installer

Situation C

Size and Type of Pipe: 24 in. (61 m) Concrete

Depth of Flow: 20% of Pipe Diameter

Length of Sewer: 1,000 ft (305 m)

Depth of Sewer: 25 ft (7.6 m)

Groundwater Elevation: 17 ft (5.2 m) above Sewer Invert

Soil Type: 0-6 Clay 6-25 Muck and Sand

Access to the Site: Open Field, OK for Vehicles

Pre-Inspection: Proved Acceptance of Liner

Excavation Requirements: Single Excavation Adequate

Building Sewer Connections: 15 Connections, Replace to Property Line

Annulus Grouting Requirements: Not Required

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(1) SDR - Size Dimension Ratio, Outside Diameter divided by wall thickness.

Manhole Seals Required:	**4 Manholes, 6 Seals**
Liner Thickness:	**SDR 17 Wall Thickness**
Mobilization Distance:	**200 mi (322 km) from Installer**

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4. Abstract from paper presented at February, 1972 Meeting of the Weed Science Society of America, by J. F. Ahrens, Connecticut Agricultural Experimental Station, Windsor, Connecticut.

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SECTION III

DESIGN STANDARDS AND CONSTRUCTION METHODS FOR THE CONTROL OF INFILTRATION AND INFLOW IN NEW SEWER SYSTEMS

In recent years there have been many improvements in pipe products, jointing systems, sewer line construction and methods of field acceptance testing. These developments have generated changes in existing applicable ASTM Standards as well as the issuance of new ASTM Standards. The purpose of this section is to provide guidance for all parties associated with the design and construction of sanitary sewers and to make them aware of the alternate choices available in sewer pipe materials, jointing systems and current, applicable national standards.

Because of the increased national attention focused on the control of I/I into sewer systems, the subjects of allowable leakage limits, suitable methods for field acceptance testing, air-tightness, photography of pipe line interiors, closed-circuit TV inspection and field determination of misalignment or excessive diametric deflection will be discussed.

In addition, recognition will be made of the fact that different types of pipe and jointing systems require different installation procedures. Different construction conditions involving rock, muck, landfills, etc. may require individual and specialized construction methods regardless of the type of pipe being installed.

Predesign Investigations

Soil and groundwater conditions: must be considered in the design if a proposed sewer system is to avoid excessive infiltration. Seasonal variations in groundwater elevation, percolation characteristics of soil strata and load-bearing capacity of undisturbed geological formations all influence potential infiltration possibilities.

Possible investigative reconnaissance procedures include:

- Geological maps.
- Aerial photographs.
- Flood records.
- Reports of previous engineering studies.
- Municipal engineer's records.
- Telephone calls to local builders, residents, utilities and contracts with public employees.
- Site visits.

Possible subsurface investigation procedures include:

- Test pits.
- Probing.
- Auger borings.
- Machine borings.
- Geophysical explorations (seismic and electrical retraction).
- Long-term monitoring of water level variations.

Soil tests---in-situ and laboratory procedures include:

- Soil classification.
- Soil performance.
- Groundwater quality and characteristics.

Soils and Soil Classification: to identify a specific soil and interpret its properties as related to infiltration conditions, it is necessary to have some knowledge of soil classification. Classification tests, such as sieve and hydrometer analyses, provide information on the physical characteristics of the soils. Test results may be useful in deciding if a material (1) is suitable for bedding and/or backfill; (2) will cause problems in dewatering as they pertain to pumping of fines and subsequent soil settlement; and (3) is likely to affect the volume, rate and quality of future flow of groundwater.

Performance tests are more specific in determining the load-bearing or permeability potential of soils. Chemical analysis of soil and groundwater may be important in some areas. Simple field classification and performance tests are available to check in-situ density of both undisturbed and recompacted soils. Commonly used field tests are the Sand Cone Method and the Rubber Balloon Method.

Soil classification systems usually include references to color, grain sizes, plasticity and cohesiveness, with interpretation as to permeability and load-bearing characteristics. For example, a "Brown course SAND, little medium GRAVEL" will indicate a cohesionless material with high permeability and groundwater flow, and probable usefulness as a bedding material. A "silty CLAY" could be interpreted as a poor bedding but likely to impede water flow to or along the sewer.

Soil studies include geology and rock formations encountered in predesign investigations. Rock types should be classified as to stratification, porosity, hardness, friability, and water-bearing or transporting characteristics. Water-laden rock formations can be as infiltration causative as water-bearing sands or gravels.

Design Allowance for I/I

Infiltration allowances are generally stated in the form of volume per unit of time, per unit of length and per unit of pipe size. The calculated volume is added to the peak design flows of domestic sewage and industrial wastes to establish pipe and wastewater treatment plant unit sizes. The peak design flow is the maximum daily rate of flow resulting from highest usage during certain hours of the day, days of the week, and weeks of the year. The design flow is based on the principle that at some specific moment, wastewater flows will be at peak volume because of the accumulation or combination of maximum usage conditions. This peak, however, may never actually occur. A number of state agencies stipulate peak design flow as a specific volume or quantity per capita. Table 11 lists design flows required by some states and provinces.

Other jurisdictions have developed peak rate curves. Figure 14 is the rate chart used by Washington, D.C.

Peak design flows must be carefully ascertained. Some design standards and designer practices, as illustrated by Table 11, lump all extraneous flows into some vague multiplier for an assumed average daily flow. Assumed I/I can vary greatly from jurisdiction to jurisdiction, e.g., from a low of 10 percent of normal sanitary flow to 100 to 200 percent based on an APWA study (1). Each designer should evaluate the conditions existing in the sewer system involved and not simply use a convenient and unsubstantiated design allowance. If arbitrary allowances are made without careful examination of local conditions and the establishment of realistic design criteria, the system may be seriously over-designed or under-designed.

As previously discussed, a goal in sewer system and wastewater management is to minimize the entry of I/I and, thereby, keep associated sewer system treatment costs at a minimum and eliminate maintenance and operating costs arising from soil fines entering the system under infiltration situations. There always will be at least a small increment of infiltration which it is not cost-effective to eliminate. The expense of the pipe, and increases in construction and inspection costs fix the lower limit for infiltration allowance. Inflow must also be carefully considered. Considerable variations in the amount of inflow may be experienced, depending on the effectiveness and permissiveness of local control with respect to sewer-use ordinances and their enforcement.

In the past some sewer designers have used such infiltration flow units as gallons or cubic feet per acre per day. This terminology is a holdover from the past, based on the old concept of storm and combined sewer design. Since an attempt now is being made to eliminate or minimize all excess water intrusions, allowances should be keyed to actual flow records or estimates from sources of flow such as per capita or per dwelling unit. Sometimes I/I rates are assumed as a percentage of the per capita flow as indicated by water use and recognized standards. Such determinations may be adequate for overall systems planning but are not sufficiently definitive for detailed final design.

An accurate estimate of I/I allowances should be divided into two basic components:

A. Infiltration Component

Since infiltration is related to tightness of pipe, manholes

TABLE 11

DESIGN FLOWS FOR SEWERS AND TREATMENT FACILITIES

A. DESIGNATED BY STATE REGULATIONS

Alberta

1) Maximum hourly flow = average daily x $\left[1 + \frac{14}{4 + p^{0.5}}\right]$

when P = population in thousands, range of maximum hourly flow is from 2 to 4 times average daily

2) Per capita average daily flow = 100 gal (378.5 1)

Illinois

1) Laterals and submains - 400 gal (1514 1) per capita per day.
2) Main, trunk and outfall sewers - 250 gal (946.3 1) per capita per day.
3) Per capita average daily flow = 100 gal (378.5 1).

New Jersey

1) Sewers designed to carry at least twice the estimated average design flow when flowing half full.
2) Per capita average daily flow = 100 gal (378.5 1).

New Hampshire

1) All sanitary sewers shall be designed to carry at least four times the estimated average design flow when full.
2) Interceptors shall be designed to carry at least two and one-half the average design flow when full.
3) Per capita average daily flow = 100 gal (378.5 1).

Oklahoma

1) Laterals and submain sewers designed for 400 gal (1514 1) per capita per day when running full.
2) Main, trunk, interceptor and outfall sewers shall have capacity of at least 250 gal (946.3 1)per capita per day when running full.
3) Per capita average daily flow = 100 gal (378.5 1).
4) The 100 gal (378.5 1) per-capita-per-day figure was assumed to cover normal infiltration, but an additional allowance should be made where conditions are especially unfavorable. This figure likewise is considered sufficient to cover flow from cellar floor drains, but is not sufficient to provide any allowance for flow from foundation drains, roof leaders, or unpolluted cooling water, which should not be discharged to sanitary sewer systems.

TABLE 11 (Continued)

Oregon

1) Because usually it is impossible to exclude all groundwater infiltration, it is recommended that the capacity of sanitary sewers when flowing full be equivalent to at least 300 gal (1135.5 l) per capita per day and preferably 350 gal (1324.8 l) per capita per day on the basis of total estimated future population. Trunk and interceptor sewers should in general have capacities equal to at least 250 gal (946.3 l) per capita per day.

Pennsylvania

1) Laterals and submain sewers - 400 gal (1514 l) per capita per day.
Main, trunk and outfall sewers - 250 gal (946.3 l) per capita per day.

2) Per capita average daily flow = 100 gal (378.5 l).

Tennessee

1) Laterals and submain sewers - 400 gal (1514 l) per capita per day.
Main, trunk and outfall sewers - 250 gal (946.3 l) per capita per day.

2) Per capita average daily flow = 100 gal (378.5 l).

Texas

1) Laterals and minor sewers shall be designed, when flowing full, assuming flows equivalent to four times average daily flow. Main trunk interceptor, and outfall sewers shall be designed when flowing full, assuming flows of 2.5 times the average daily flow.

2) Per capita average daily flow = 100 gal (378.5 l).

Utah

1) Laterals and submain sewers - 400 gal (1514 l) per capita per day
Main, trunk and outfall sewers - 250 gal (946.3 l) per capita per day.

2) Per capita average daily flow = 100 gal (378.5 l).

Source: "Prevention & Correction of Excessive Infiltration & Inflow into Sewer Systems--A Manual of Practice", #11022EFF 01/71 Prepared for USEPA by APWA.

TABLE 11 (Continued)

B. LOCAL AUTHORITY POLICIES AND ACTIONS

	Allowable Infiltration	(Metric)
Local Authority	Gal/In-Dia/ Mi /Day	1/ Cm-Dia/ Km/Day
Hartford, CT.	200	185.2
New York, NY.	250-500	231.5-463
Philadelphia, PA.	2,000	1852
Hampton Rds., S.D., VA.	500	463
Miami-Dade Co. W&B Auth.	200	185.2
Louis. J.H. Co. KY.	300	277.8
Louis.-Dav. Co. TN.	200	185.2
MSD Chicago, IL.	500	463
Detroit Metro, MI.	250	231.5
Wayne Co., MI.	200	185.2
MED Cinn. OH.	150	138.9
Dayton, OH.	500	463
MSB, St Paul, MN.	100	92.6
MSB, Milwaukee, WI.	200	185.2
New Orleans, LA.	200	185.2
Dallas, TX.	200	185.2
Ft. Worth, TX.	150	138.9
Witchita, KS.	180	166.7
Kansas City, MO.	200	185.2
St. Louis, MO.	200	185.2
MSD, Denver, CO.	200	185.2
Orange Co., CA.	190	175.9
Sacramento, CA.	500	463
Metro, Seattle, WA.	600	555.6

Source: "An Analysis of the Environmental Protection Agency Needs Survey," April, 1975, prepared for National Commission on Water Quality by APWA.

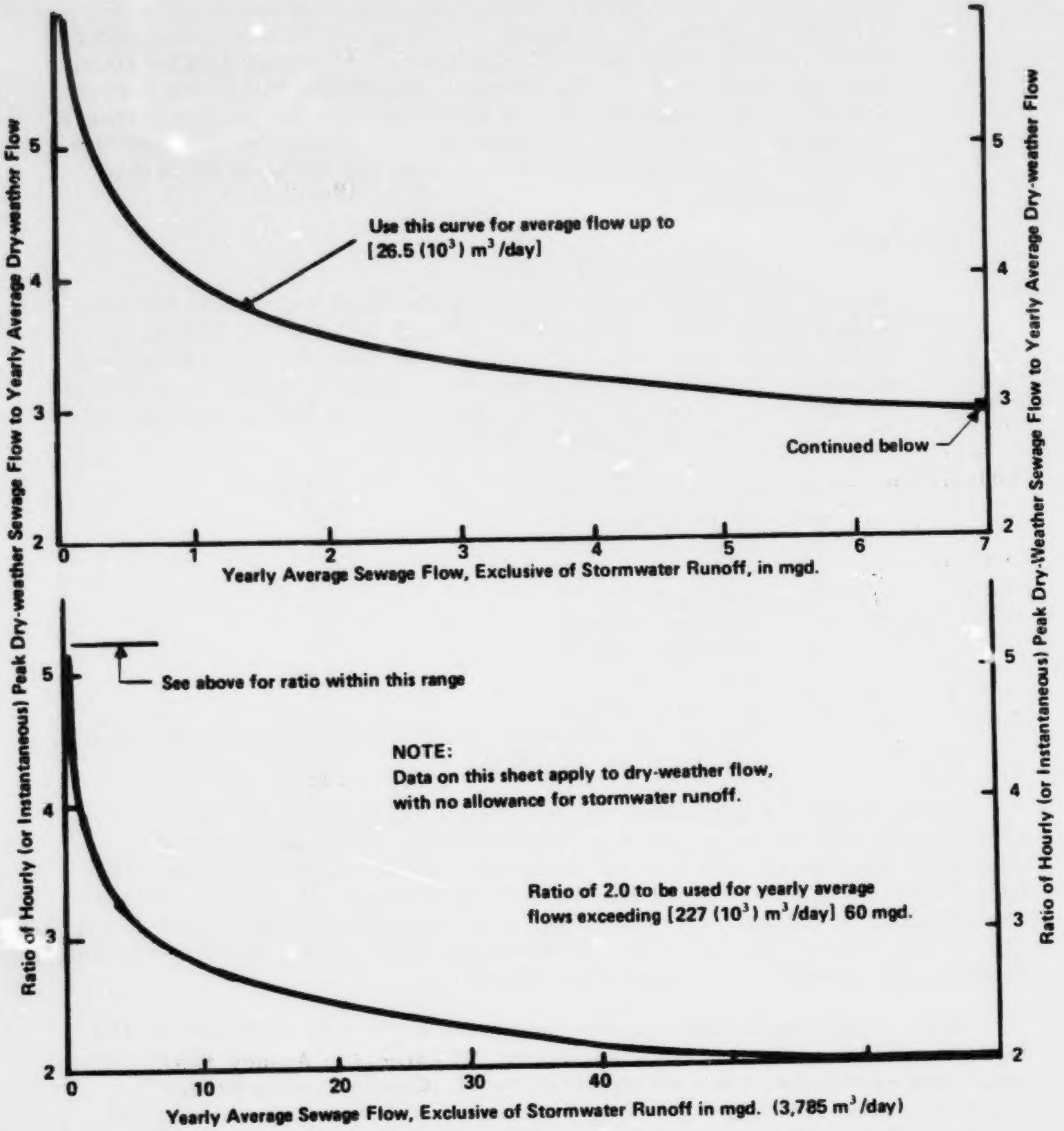


Figure 14. Ratio of peak sewage flow to average flow.

Source: District of Columbia Department of Sanitary Engineering

and other structures such as pump stations, any design allowance should be correlated with the maximum allowable construction infiltration allowances. While the full discussion of construction allowances is contained later in this section, it is sufficient to note that any amounts of permitted infiltration must be considered in the design. In effect then, the design infiltration component should be a function of the infiltration allowance used in this relationship and should be the maximum allowable system average, rather than the maximum allowable between manholes.

B. Inflow Component

Where a new sewer system is being designed in a jurisdiction that forbids the interconnection of any drainage, storm, or clean waters and where enforcement is complete and effective, there would be no inflow component. Such a system is difficult to achieve; to accomplish it the following inflow sources would have to be prohibited and enforced:

- Roof downspouts.
- Foundation drains.
- Basement drains.
- Basement sumps and/or capped clean-outs.
- Sump pumps.
- Areaway drains.
- Driveway drains.
- Yard drains.
- Street drains.
- Perforated or poorly sealed manhole covers in areas of potential flooding.

Since initial achievement and continued realization of such restrictions are never completely realized, the acceptable inflow component must be an engineering judgement factor tailored to fit the individual local situation. In terms of an average per capita sanitary contribution of 100 gal (378.5 l) per day, an inflow component of 5 gal (19 l) per capita per day might be chosen or some amount determined from previous I/I studies for comparable areas.

When local regulations permit connections of "clean water" to the separate sanitary system and they cannot be tightened by any amount of logic and persuasion used to convince local officials, the design engineer should develop inflow or stormwater allowance curves for the system. These curves result from studies of permitted inflow in terms of paved areas per dwelling unit or per person and in consideration of a certain maximum storm toleration. Figure 15 was developed by the District of Columbia, Sanitary Engineering Department, which has selected a 15-year storm as the design storm. Figure 16 shows the stormwater allowance curves for a design storm falling on various acreage areas with varying population densities. These represent an attempt to correlate lot or plot area with population. A straight-forward use of

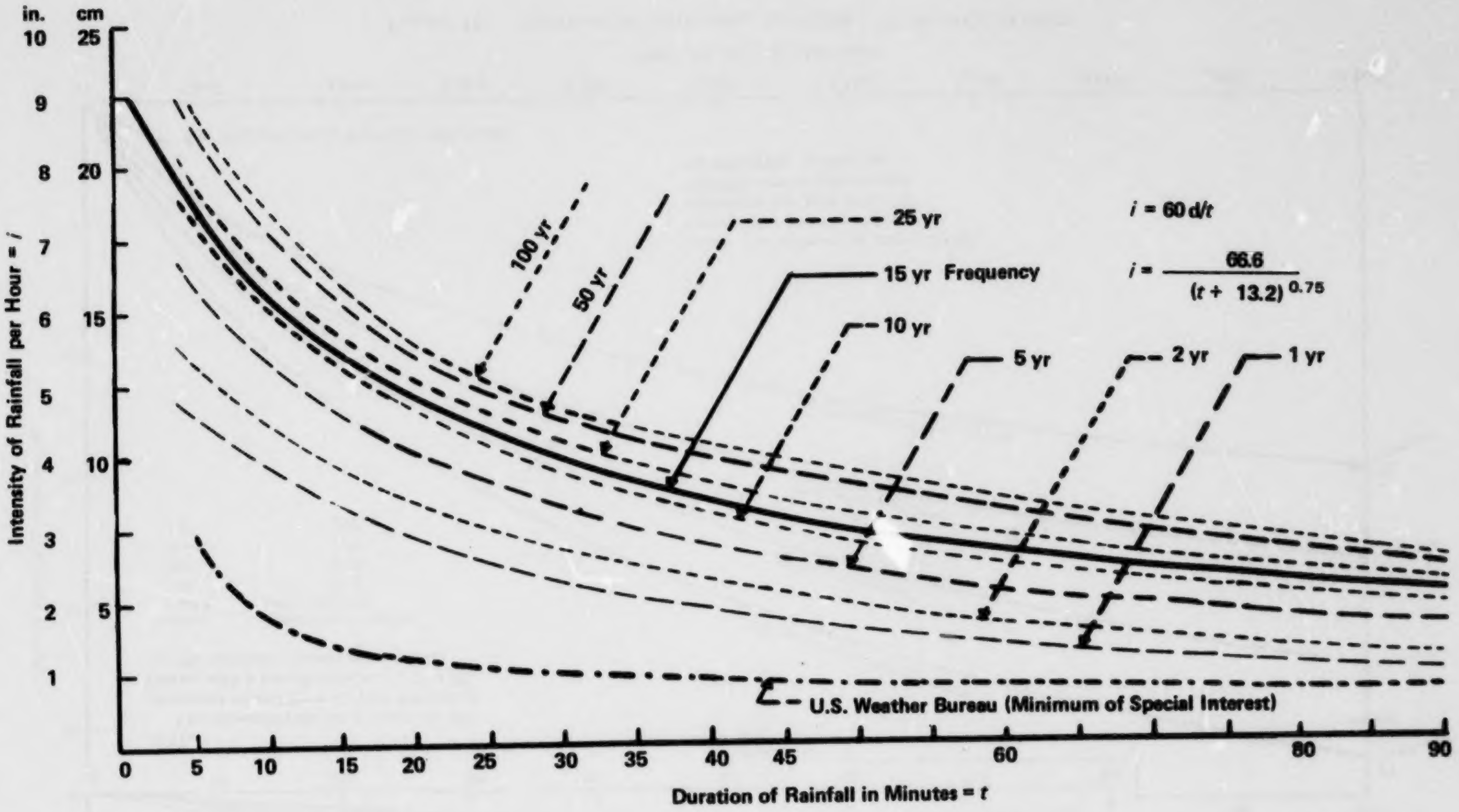
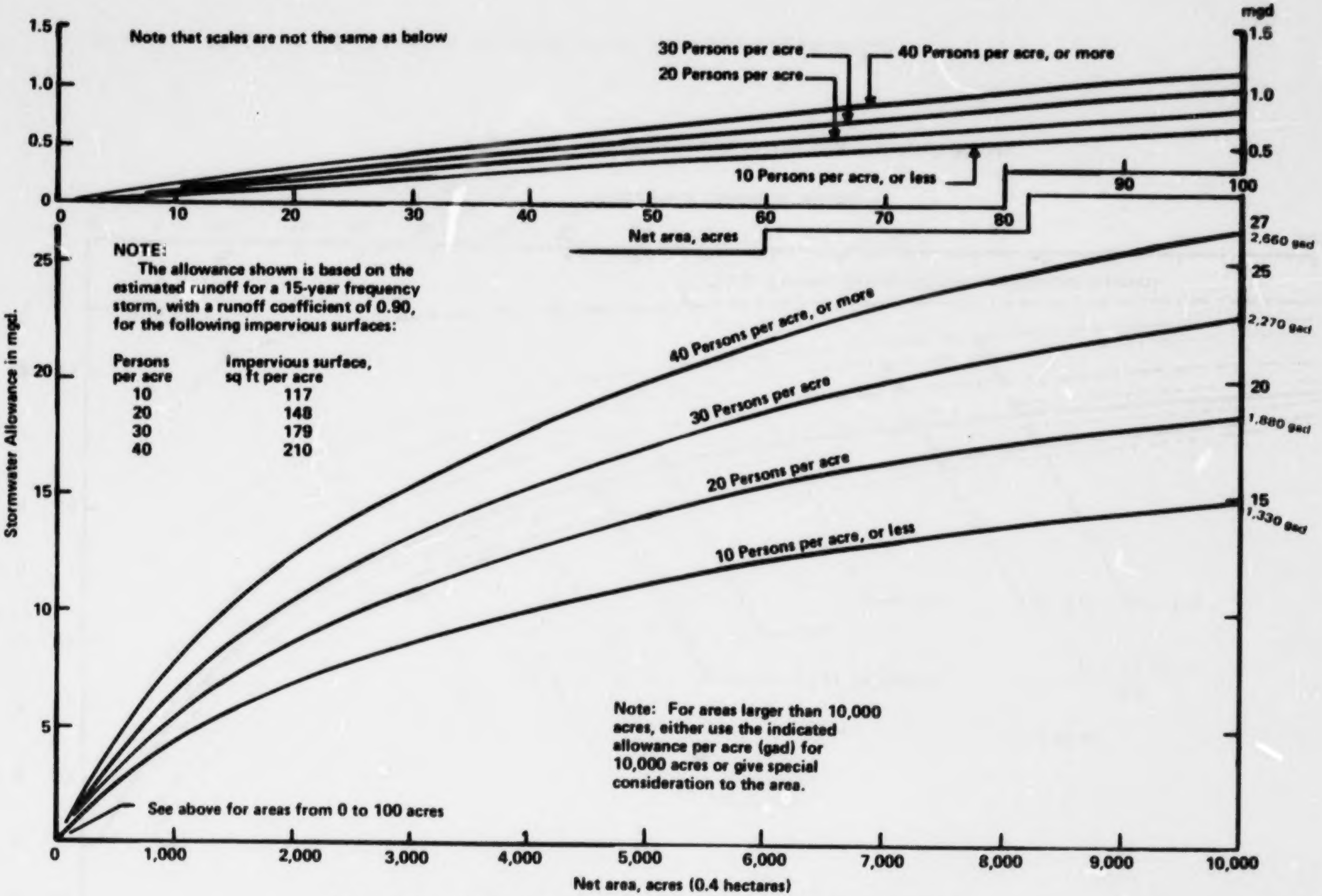


Figure 15. Intensity-duration-frequency rainfall curves.

Source: District of Columbia Department of Sanitary Engineering



NOTE:
The allowance shown is based on the estimated runoff for a 15-year frequency storm, with a runoff coefficient of 0.90, for the following impervious surfaces:

Persons per acre	Impervious surface, sq ft per acre
10	117
20	148
30	179
40	210

Note: For areas larger than 10,000 acres, either use the indicated allowance per acre (gad) for 10,000 acres or give special consideration to the area.

Figure 16. Stormwater allowance for design of separate sewers.

Source: District of Columbia Department of Sanitary Engineering

infiltration or inflow criteria on strictly an area basis becomes meaningless when population development or potential development is ignored.

The District of Columbia charts are useful as an illustration of the concept of inflow component allowances. However, they also incorporate a flat 700 gal/ac (6,625 1/ha) per day figure representing yearly average flow of groundwater infiltration. Such an assumption does not take into account varying lengths of pipe, population densities, and types of buildings. Four hundred people/ac (1,000/ha) in high rise apartments would produce considerable less infiltration potential than 285 people in 70 single-family homes on 0.5 ac (0.2 ha) lots. However, in a combined system such as in the District of Columbia, which also permits outside areaway drains, the infiltration load is of less significance.

Example 7 illustrates the use of design I/I allowances and the varying impact on resultant flows. These may or may not apply to conditions existent in other jurisdictions. A basic design assumption is that infiltration and inflow represent additional volume, over and above the peak domestic flow of four times the average daily flow.

EXAMPLE 7
ILLUSTRATION OF DESIGN I/I ALLOWANCE CALCULATIONS

Assumed Conditions: Tight system with no permitted inflow

Area 1,200 ac (486 ha)

Population Density - 20 persons/ac (0.2 ha)

Total Population - 24,000

Separate Sanitary System

4 in. (10.2 cm) building sewers - 36 mi (57.9 km)
8 in. (20.3 cm) street laterals - 24 mi (38.7 km)
10 in. (25.4 cm) sub-trunks - 6 mi (9.7 km)
12 in. (30.5 cm) trunk - 6 mi (9.7 km)

Average Daily Per Capita Sanitary Contribution - 80 gal (302.8 1)

Peak Design Flow - 3 times average daily flow

Additional Assumptions:

Design Infiltration Component = 200 gal/in.-diam/mi/day (185.2 1/cm-diam/km/day).

Maximum Inflow = 5 gal/person/day (19 1 /person/day)

Maximum Infiltration Component

800 gal/mi/day x 36 mi = 28,800 gal/day (109,008 1/day)
1600 gal/mi/day x 24 mi = 38.400 gal/day (145,344 1/day)
2000 gal/mi/day x 6 mi = 12,000 gal/day (45,420 1/day)
2400 gal/mi/day x 6 mi = 14,400 gal/day (54,504 1/day)
Total 93,600 gal/day (354,276 1/day)

EXAMPLE 7 (Continued)

Maximum Inflow Component

5 gal/person/day (19 l/person/day) x 24,000
= 120,000 gal/day (454,200 l/day)

Total Maximum I/I Component = 213,600 gal/day (808,476 l/day).

Peak Design Flow

80 gal/person/day (302.8 l/person/day) x 24,000 x 3
= 5,760,000 gal/day (21,801,600 l/day).

Total Peak Design Flow = 5,973,600 gal/day (22,610,076 l/day)
or
(22,610 m^3/day)

Additional Assumed Conditions for System Slightly Less Tight and Some Areaway Drains Permitted

Design Infiltration Component = 500 gal/in.-diam/mi/day (463 l/cm-diam/km/day)

Inflow Calculated from Washington, D.C. Stormwater Allowance Curve (Figure 16)

Maximum Infiltration Component:

2,000 gal/mi/day x 36 mi = 72,000 gal/day (272,520 l/day)
4,000 gal/mi/day x 24 mi = 96,000 gal/day (363,360 l/day)
5,000 gal/mi/day x 6 mi = 30,000 gal/day (113,550 l/day)
6,000 gal/mi/day x 6 mi = 36,000 gal/day (136,260 l/day)

Maximum Total Infiltration Component = 234,000 gal/day
(885,690 l/day)

Inflow Component from Figure 16 = 6,000,000 gal/day
(22,710,000 l/day)

Total Infiltration/Inflow = 6,234,000 gal/day
(23,595,690 l/day)

Peak Design Flow = 80 gal/person/day (302.8 l/person/day)
x 24,000 x 3 = 5,760,000 gal/day
(21,801,600 l/day)

Total Peak Domestic Design Flow = 11,994,000 gal/day
(45,397,290 l/day)
or
(45,397 m^3/day).

The example not only illustrates the methods for arriving at peak design flows; it also shows how, in the same theoretical design area, seemingly small variations in design criteria can result in great differences in flows and pipe sizes.

The increase in the design infiltration component from 200 to 500 gal/mi/in-dia/day (185.2 to 463 l/km/cm-dia/day) raises the total infiltration from 2 to 5 percent of the sanitary flow. In terms of actual volumes, the 500 gal/mi/in-dia/day (463 l/km/cm-dia/day) allowance, which is in use at the time, would permit entry of a maximum of 85.6 mg (324,000 m^3) of extraneous water per year.

The most striking change in extraneous water flow occurs in the inflow component of the additional assumed conditions, utilizing the Washington, D.C. design curves for stormwater (inflow) into separate sanitary sewers. In this case the inflow alone is 6 mgd (22,710 m^3/day) which almost equals the peak sanitary design flow and dwarfs the infiltration component even in its increased condition.

This illustrative example is over-simplified in order to emphasize the impact of differing design and construction allowances. In actual practice pipe sizes would be varied according to the design flows in a slightly more involved procedure.

Gravity Sewer Pipe and Jointing Materials

Types of Sewer Pipe

Improvements and developments in pipe materials ensure that the designer can provide proper materials to meet rigid infiltration allowances. The basic question of water-tightness of pipe material should be of as much concern as problems of structural integrity and chemical characteristics of the wastewater to be handled. In addition, local soil, gradient, or special installation conditions could make one pipe material more appropriate than another in specific instances.

The design of sewer lines which will be operated under pressure must be carefully evaluated. The pressures to be used may have a direct impact on the decision as to the type of pipe which must be used. However, pressure-type sewer systems are beyond the scope of this manual; the data herein relate to gravity sewer systems.

Appendix F was adapted from information published by the American Society for Testing and Materials (ASTM) from their Standards for Selected Sewer Pipe and Appurtenances.

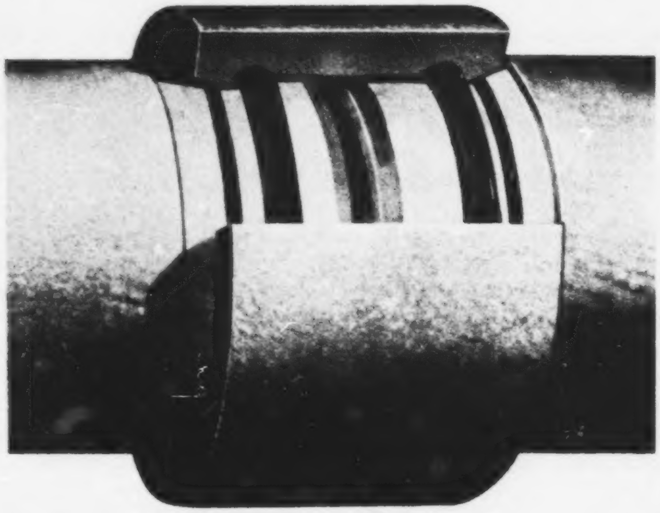
Sewer Jointing to Control Infiltration

The effectiveness of sewer joints for the control of infiltration is so important that no sewer system is better than its joints. A good joint must be water-tight, root penetration-tight, resistant to the effects of soil and wastewater, and long-lasting.

It should be recognized by the engineer, however, that field performance represents the sum of the manufactured joint characteristics and the contractor's installation practices. None of the currently produced jointing systems for the various types of sewer pipe is absolutely fool-proof. However, each has inherent capabilities which, when combined with appropriate installation procedures, will provide excellent field performance.

The following methods of jointing are used in sewer service with the listed types of pipe:

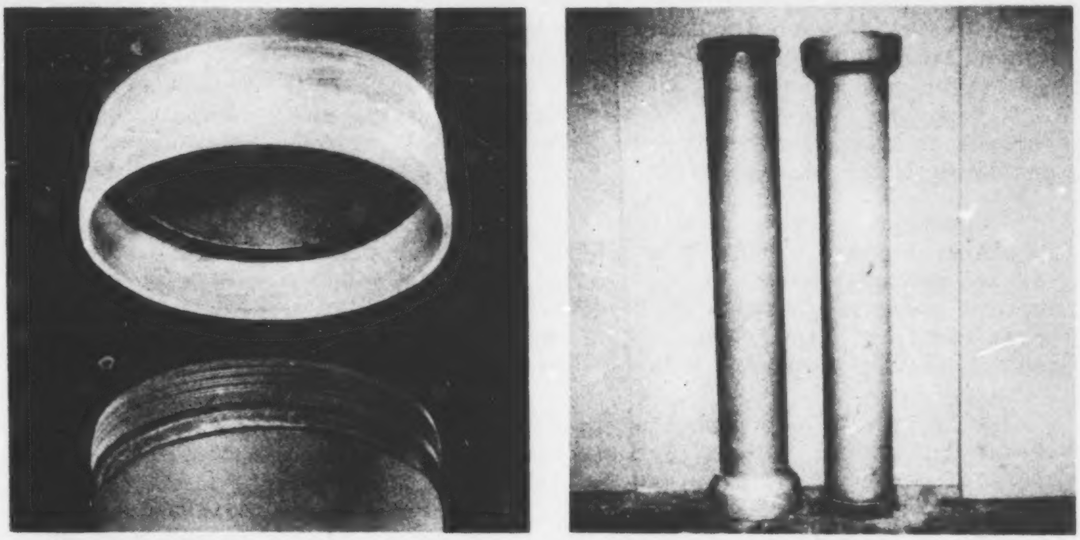
Asbestos-Cement Pipe--Asbestos-cement sewer pipe joints consist of a sleeve coupling and two rubber gaskets. The gaskets, which are positioned in grooves situated in the coupling sleeves, are compressed between the finished pipe ends and the coupling grooves. Joint design and assembly provide separation of the pipe ends to provide joint flexibility. Figure 17 shows a typical joint.



Courtesy: Certain-teed Products Corporation

Figure 17. Typical asbestos cement sewer pipe joint.

Clay Pipe--Several jointing systems are in common usage in various areas of the country and examples are shown in Figure 18.



Source: United States Concrete Pipe Company

a. No Bell

Source: Logan Clay Pipe Company

b. Bell

Figure 18. Clay pipe sewer joints.

For bell and spigot pipe, most manufacturers supply a factory-applied compression joint in which a filled plastic thermosetting resin is applied to produce concentric surfaces in the bell and on the spigot. In some designs an elastomeric resin, such as urethane or plasticized PVC is molded into an annular bead or fin pattern on one or both castings to act as the sealing device. Where the resin is rigid, a separate O-ring rubber gasket, positioned in a groove in the spigot resin, is the compression sealing unit.

Plain-end clay pipe, i.e., without clay bell, is now being supplied by many manufacturers with a factory-applied joint.

Such joints include:

1. A rigid socket PVC or glass-reinforced thermosetting resin attached to one end and a sealing device of urethane elastomer or conventional O-ring rubber gasket system on the other.
2. A urethane elastomer on both ends with a rigid PVC or glass-reinforced thermoplastic external coupling sleeve. Sealing beads may be in the sleeve or on the spigot.
3. True plain end pipe may be coupled with an external sleeve of rubber or elastomeric plastic, tightened in place with stainless steel circumferential bands.

This third type is offered for both new construction and repairs, or adjustments to field laying length conditions.

Concrete Pipe--Each concrete pipe is provided with a male joint (spigot or tongue) and a female joint (bell or groove) formed integrally with the pipe wall.

Circular concrete pipe for sanitary sewers is provided with internal, compression-type joints, in which the natural and/or synthetic rubber gaskets are compressed in the annular space between the mating surfaces to form a watertight seal when installed. Joint geometry and gasket cross-sectional shapes vary, but in every type the gasket is the sole sealing element depended upon to make the joint flexible and watertight.

Non-circular concrete pipe is not compatible with the use of interior rubber gasket joints. Satisfactory results have been obtained with these shapes by the use of external elastomeric bands or carefully applied mastic fillers for the joints. A relatively successful innovation in this latter type involves the use of preformed mastic segments which facilitate handling and provide uniform applications

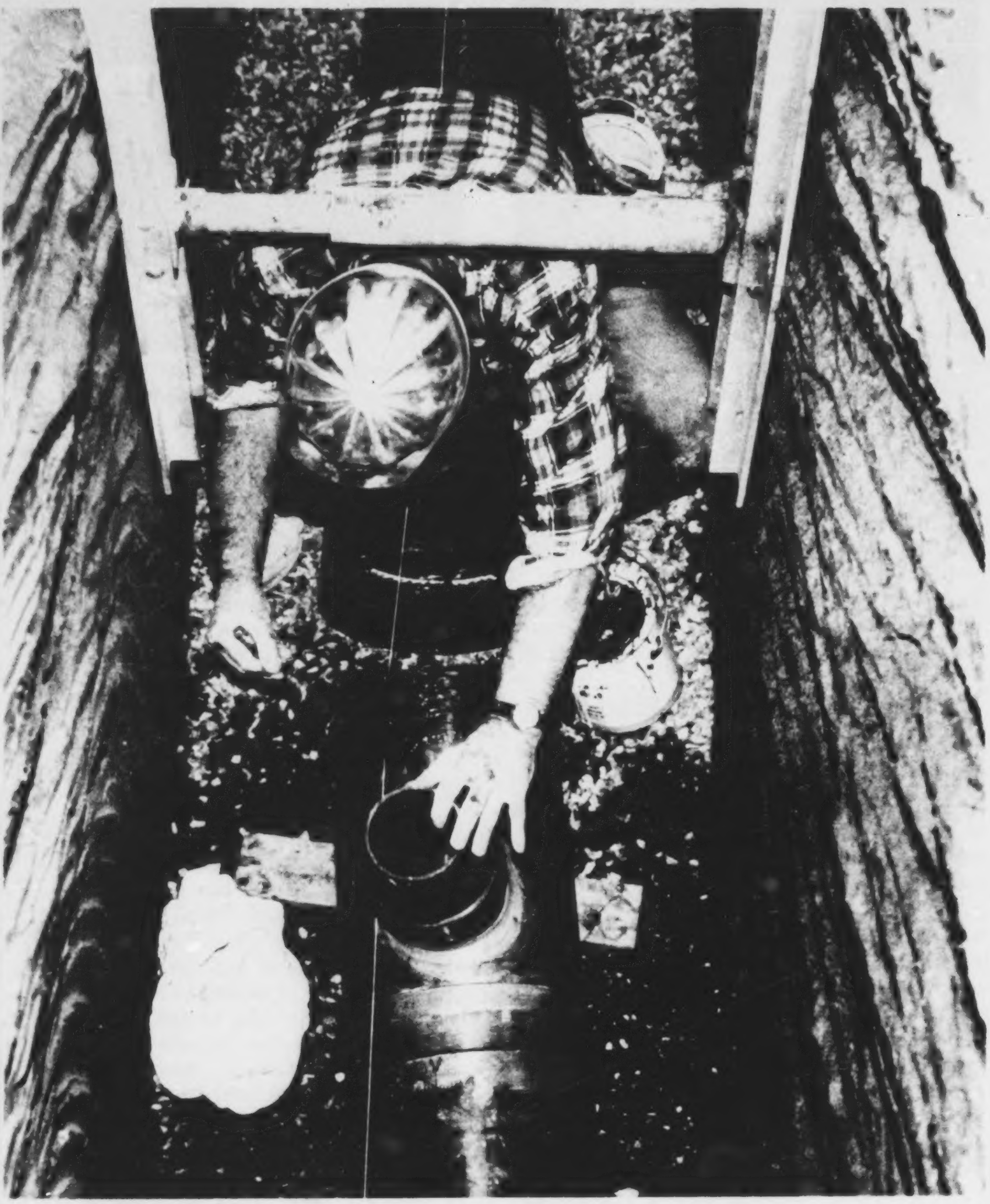
Plastic Pipe--Low profile sockets for plastic pipe may be either extruded and belled slightly to receive the spigot or cemented to the pipe subsequent to extrusion.

Acrylonitrile-Butadiene-Styrene (ABS) pipe is jointed by a sleeve socket solvent cemented to one end by the manufacturer and sealed by either a solvent cement method or rubber gasket. In the solvent cement method, the spigot is wedged and rotated into the tapered socket and the two surfaces are fused together by the solvent. In the gasket method, the coupling is double-belled to provide proper positioning for the gasket and a gasket stop is cemented on the spigot to retain the gasket in compression.

Polyvinyl chloride (PVC) pipe may be jointed either by a solvent cement system or rubber gaskets. In the solvent cement joint, the pipe spigot is wedged into the tapered socket and the two surfaces fused together by the socket. Rubber gasketed joints utilize rubber rings placed inside the bell. A typical joint is shown in Figure 19.

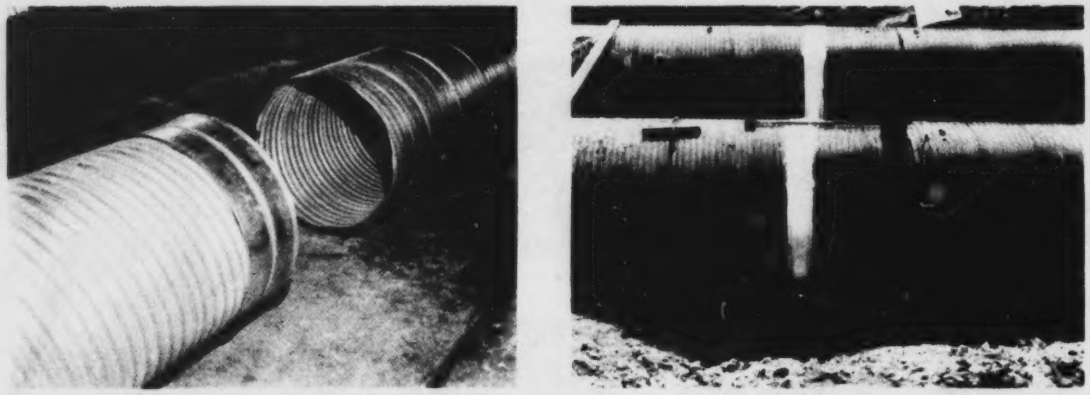
Steel Pipe--Corrugated metal pipe as used for sanitary sewers has joints which are sealed either by flat rubber gaskets spanning the joint and tightened against the two adjacent pipes by exterior coupling bands or with a proprietary joint incorporating two "O" Rings seated in the pipe end corrugations. Pipe is available in diameters of 142 in (3.6 m) or more. Figure 20 shows a typical joint.

Jointing under in-the-wet and difficult-to-see conditions does not lend itself to precise and careful workmanship. Regardless of the type of pipe and jointing system used, it is important that engineering inspectors caution contractors to clean the jointing elements immediately



Courtesy: Armco Steel Corporation

Figure 19. PVC pipe joint.



Source: National Corrugated Steel Pipe Association

Snug-fitting sleeve joint holds corrugated steel pipe together and resists shearing forces of soil settlement. No bolting is necessary.

Use of "hugger-type" connection on large storm sewer job. Special wrench draws band tight.

Figure 20. Steel pipe sewer joint.

prior to use. When using compression seals, such as O-ring gaskets, the mating units should be adequately lubricated, unless the gasket is intended to be rolled into position, in which case it and the mating surfaces should not be lubricated. In the case of solvent-welded joints, the mating surfaces should be thoroughly coated with the proper solvent and immediately joined. Subsequent field performance tests with air or water should demonstrate the efficacy of the pipe and joints.

Effect of Subsurface and Groundwater Conditions

Groundwater conditions may vary seasonally or the subsurface may be constantly dry or wet. Where possible the existing groundwater level should be lowered by dewatering procedures during construction in order that a firm foundation be attained. However, the engineer must be aware of the fact that once the dewatering procedures are terminated the natural groundwater level will be reattained and its presence may introduce the possibility of groundwater infiltration into the completed sewer. In addition, the designer must consider the possibility that "soft" foundations may lead to eventual differential settlement and the possible opening of the sewer pipe joints. The existence of differential settlement may dictate the need for flexibility at the joints in order to accommodate some pipe deflection. Whenever possible, the foundation should be improved to minimize future maintenance problems. Most of the types of pipe listed in this Manual of Practice are available with some type of flexible joint.

In order to assure the long term structural and functional integrity of new sewer construction, one of the most basic considerations should be the control or minimization of settlement by providing an adequate foundation for the pipe. The potential for settlement, including differential settlement, can vary widely under different naturally occurring soil conditions. Extensive soil investigations, testing and expert geological evaluation may be required in some cases to determine the appropriate control techniques to be applied. Where minor settlements within an acceptable order of magnitude are anticipated, proper selection of pipe strength and flexibility at the joint to permit a limited amount of movement without structural hazard or loss of seal should be emphasized. Selection of the joint may also be based on its shear transmitting capability since differential settlement can cause stress to be transmitted through the joint.

A chemical analysis of groundwater may sometimes be useful where the sewer will be installed below groundwater or in trench conditions where the trench backfill material may act as an aquifer. In some cases the proper selection of pipe materials will depend on adequate soil and groundwater tests.

Manhole and Cover Design

It is known that an important part of the total I/I into existing sewer systems enters at manholes and specifically at connections of pipe to manholes. Significant progress has been made to reduce leakage from these sources, but special consideration in design and construction remains important.

Brick and block manhole construction methods are less used today because of the reduced availability of skilled masons in the sewer construction field and the rising labor costs for such methods. Precast concrete manholes have gained wide acceptance because of the convenience of installation as shown in Figure 21. Precast manholes properly joined with rubber gaskets or sealing compounds have been found to be watertight. Early versions of precast structures incorporated cast-in-place bases on which the riser elements were installed. The next stage added a precast base in which holes were provided to accommodate the incoming and existing pipe lines. In the field these openings were mortared closed to provide a watertight seal. However, connections between manholes and pipe became rigid as the concrete cured and some structural failure ensued when differential settlement occurred between the pipe and manholes. Subsequently, short stubs of pipe were provided to allow the flexibility in the pipe joints to accommodate differential settlement. More recently, a number of flexible manhole connections have been devised and are in common use.

Manhole cover design is attracting more serious attention in view of evidence that even small casting perforations can produce sizeable contributions of extraneous inflow. It has been estimated that a single 1 in (2.54 cm) diameter hole in a manhole top covered with 6 in. (15.2 cm) of water may produce an inflow of 11,545 gal (43.7 m^3) per day; this exceeds the infiltration or the inflow components in Example 7. Appendix A is a report of laboratory testings of the flow through a manhole cover compared to the head on the cover.

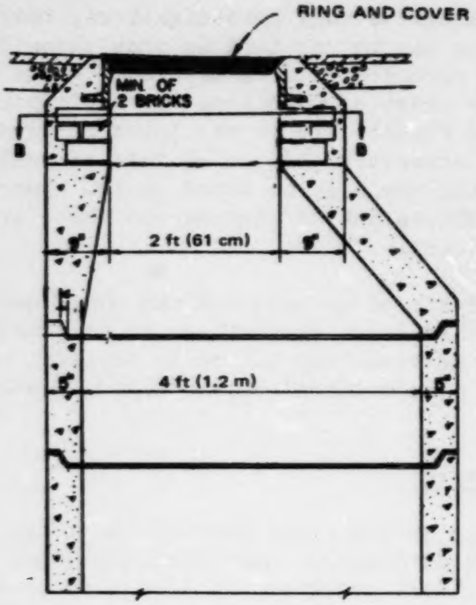


Figure 21. Precast concrete manhole.

Obviously, manholes located in areas subject to flooding should have solid, sealed covers. Such covers, however, often prevent adequate ventilation of the manhole and sewer, posing danger to maintenance employees. Thus, the design of sections requiring sealed covers should be given special care. Maintenance employees should check all manholes for hazardous gases prior to entering. It should be pointed out that most manhole covers are not subject to inundation and extraneous inflows and, therefore, perforations for adequate ventilation should be provided in most cases.

Practical and Maintainable Design

Recent investigations into sewer design problems have revealed a serious lack of understanding and communications between design engineers and maintenance personnel. There are many sewer problems caused not only by inadequate hydraulic design but also by impossible physical structures with extended lengths of pipe, omitted manholes, curved lines on difficult radii, and inaccessible chambers. Such design deficiencies result in inadequate maintenance and unauthorized overflows, and usually prevent rapid and adequate I/I surveys.

A sewer system cannot be buried and forgotten. Every effort must be made to guarantee its maximum useable and economic life.

Construction Methods and Inspection

Leakage in sewer systems is directly related to pipe product characteristics, soil and groundwater conditions, and to the manner in which installation is accomplished. All the sewer pipe listed previously, when installed properly, will remain reasonably leak-free for the design life of the system. Total costs will vary, depending on the relative care employed by the inspector and contractor during installation, as well as the competence of the designer in specifying material and installation details and acceptance criteria.

Pipe Characteristics

Pipe characteristics have a definite bearing on how installation should be carried out. In general, pipe types fall into two broad structural categories: rigid pipe and flexible pipe. Some types of pipe have both rigid and flexible characteristics. Pipe in each category reacts differently under various soil conditions.

Rigid pipe is designed and manufactured to provide sufficient ring strength to resist anticipated field loads. Flexible pipe must, however, obtain adequate support from the side fills to resist over-deflection.

Construction Contract Documents Related to Soils and Groundwater

Soils and groundwater information used in the design must be made available to the construction contractor. These data are required to evaluate the need for, or the design of, sheeting, dewatering, borrow material, and a number of other considerations which influence construction cost estimates. Since the nature of soils and location of groundwater levels to be encountered is of prime importance for sewer work, all subsurface information obtained should form a part of the contract documents. Each subsurface exploration should be clearly located on an overall site plan since the data obtained from the exploration are directly applicable to that particular area. Care should be taken to avoid possible misinterpretation or misrepresentation. For example, groundwater table elevation should be accompanied with the date of such observation; soil and rock profiles developed from subsurface explorations should reflect extrapolation between investigation locations and predict the conditions most likely to prevail. The widely used exculpatory notes which in effect say to the contractor: "We are not responsible for any information supplied," may not be acceptable in a court of law and may result in higher bid prices due to the contractor's uncertainty as to what underground conditions he will encounter.

Designers and field construction personnel should be alert to the current regulations and requirements of the Occupational Safety and Health Administration (OSHA).

Trenching and Excavation Methods

Trench excavation is done by hand or by machine, depending on the location and magnitude of excavation required. For most trenching work, excavation by machine is more economical and efficient. Machines particularly adapted to sewer trench excavation include continuous bucket excavators, overhead cableway or track excavators, power shovels or backhoes and boom and bucket excavators.

Within the framework of OSHA regulations, trenches should be as narrow as possible but wide enough to permit proper laying of pipe, inspection of joints, and consolidation of backfill. Depending on the type of soil, space available, groundwater level, length of time the excavation is to remain open, and depth of excavation, the slopes are constructed as steeply as they will stand without caving. In some areas a minimum slope of 1:1 is specified or shoring in a vertical trench is required. For deep excavations, particularly below the groundwater table, the excavation must be braced or sheeted to ensure safe working conditions.

Construction should be accomplished in dry conditions; thus, if water is encountered in the excavation, dewatering should be done by sump pumping, use of well-point systems, or deep wells, etc.

Foundations

The foundation is that zone below the bedding which normally immediately supports the pipe and joints. The foundation should be made sufficiently firm by over-excavation and placement of foundation material where needed to provide a working surface capable of supporting foot traffic with no more than minor tracking. Hard material should be excavated so as to provide a reasonably uniform layer of bedding material of a specified thickness. At points of transition from hard to soft native material, both should be over-excavated as required by the engineer, tapered out over a suitable distance, and replaced with compacted foundation material. The purpose of these provisions is to assure reasonably uniform supporting strength along the trench, so as to avoid concentrated loading or differential settlement.

Bedding

Bedding is that zone above the foundation which supports the pipe. Bedding material may be original ground, sand, gravel, crushed stone, oyster shells, slag, concrete or other suitable materials that meet job requirements. Locally available materials account for the wide range of suitable bedding materials. Non-uniform bedding can result in pipe settlement and creation of infiltration conditions.

In some instances material with high void ratios (such as trap rock or clam shells) produce a watercourse around the pipe. It is extremely important that pipe installation and inspection be carefully performed to preclude heavy infiltration from this type of aquifer.

Specific information on recommended bedding of various types of pipe are available from individual pipe companies or associations. ASCE Manual of Practice No. 37--WPCF Manual Practice No. 9, ASTM recommended installation practices, and other references contain installation instructions which, when applied, will help produce tight sewers.

Backfill

Backfill is that zone above the bedded pipe, and extending to the ground surface. Backfill is further divided into two sub-zones: the zone around and over a pipe to a specified depth of cover; and that zone encompassing the remainder of the backfill operation. Backfill in the pipe zone should be made with selected materials. The remainder of the backfill is generally governed by the type of material initially excavated. Frozen earth, rubbish, old timber, and similar materials should be avoided where permanent finished surfaces are desired because such materials decompose or soften and can cause eventual surface settlement.

Depending primarily on the location of the sewer and the anticipated development of the area, specifications may require a specific gradation of backfill material, as well as definite compaction requirements. In this case, the proposed fill must be laboratory-tested to determine its gradation and compactive characteristics.

Compaction Techniques

Regardless of location and pipe material used, the most critical area with respect to compaction is directly around the sewer pipe. The backfill should be placed and packed by hand under and around the pipe and compacted by light hand tampers. Compaction of sidefill may not always be needed for rigid wall pipe, but is essential for flexible pipe susceptible to deflection. As backfilling is continued to original surface level, compaction can be achieved by machines. The entire trench width must be compacted. Depending on the size of the excavation to be filled, compacting equipment will range from hand-operated compacters to large rollers.

Operational Problems

A number of commonly experienced problems deal with pipe and equipment handling. Rough pulling of trench sheeting or advancing trench boxes or shields without holding already installed pipe in position can cause joints to open and result in eventual leaks.

Flowing or high water in an open trench during pipe jointing tends to cause leaks. Water in solvent welding and soil particles in the pipe bell or on the spigot in either rigid or flexible joints tend to impair the integrity of the finished joints. Failure to comply with the engineer's or manufacturer's jointing instructions is probably the most common cause for failure found in infiltration/exfiltration tests. Often this can be traced to inadequate preconstruction conferences or failure to impart instructions for pipe laying operations. This not only applies to jointing pipe but also to making house service connections.

Inspection of Construction

Inadequate inspection and lack of technically consistent field supervision are a far greater cause of ineffective sewer installation than generally recognized. All too often lack of good inspection results in failure to comply with engineering specifications. When experienced and conscientious supervision is provided, the incidence of leakage test failures is significantly low and long-term system performance is greatly improved. This aspect cannot be overemphasized, particularly in this inflationary age where the tendency is to economize to meet budgetary limits. Nothing could be more "penny-wise but dollar foolish" than to skimp on inspection control of sewer system construction.

Dewatering Techniques

Excavations can be dewatered by sump pumping, a well-point system, deep wells, or soil solidification. Pumping from sump pits is most widely used for shallow excavations when the quantity of water is small and the water table need not be lowered any great distance. Well-point systems and deep wells are more complex and should be designed by an engineer. In any well-pointing procedure, caution should be exercised in making certain that the groundwater table will be restored after construction at approximately the same rate or in a comparable period of time that it took to draw down the water level. This procedure will prevent any sudden "surge" of water which could conceivably exert enough force to cause disruption of newly constructed sewer lines or manholes.

Some areas, notably in gulf or ocean coastal areas, have an underlying groundwater and type of soil or porous rock which cannot be dewatered. In some cases it has been found possible for a contractor to install pipe by using divers. In such cases, pipe is brought to line and grade by the use of sand bags placed at the joint end and alignment is achieved by control of laser beams or string line. In such cases, the line is checked for water-tightness after completion of a section of sewer between manholes where it is possible to dewater the system and check for infiltration. This is not generally recommended practice, but it is a practice that is carried out in certain areas of the United States.

Construction Inspection and Testing of Soils, Bedding and Backfill

Infiltration of groundwater into a proposed sewer system can be minimized by proper construction procedures, rigid inspection of materials and methods of installation, and performance of soil and groundwater tests and the resulting correction of problems determined including:

- Field Inspection of Excavation, Bedding and Backfill: construction procedures and materials should be inspected for conformance with project plans and specifications. Rigid inspection is mandatory.
- Field Soil Tests: field soil testing is used in conjunction with controlled backfill. When specifications require backfill to be compacted to a high percentage of maximum density, in-situ field density tests must be performed to determine if such compaction is achieved. The most common means of field density testing are the Sand Cone Method and Rubber Ballon Method (2),both yielding a field density to be compared with laboratory maximum density in order to monitor degree of compaction.
- Laboratory Testing: for projects specifying a specific gradation requirement for trench backfill or bedding, the proposed material should be subjected to sieve and/or hydrometer analyses. Further, a compaction test should be performed if specifications call for a required degree of compaction.
- On Site Testing: modern soil density devices have been proven effective and expeditious for field applications.

Construction Leakage Allowances

The most effective way to control infiltration, and at the same time to assure the structural quality and condition of the new installation, is to establish and enforce a maximum leakage limit as a condition of job acceptance. Leakage allowances may be stated in terms of water infiltration or exfiltration, or exfiltration of low-pressure air. They should be stated in terms of both maximum allowable rate per test section and maximum allowable average rate for the total project. Manholes should be included in the allowances, or separate manhole test allowances should be specified.

Infiltration--

Since optimum minimization of infiltration is the desired objective direct measurement of infiltration would appear to be the preferred procedure. Measurements must be made, however, before any service connections are functioning, and also at a time when groundwater is over the entire test section of pipe and at or near its maximum level. This combination of circumstances is rare and therefore infiltration testing is practical only in a limited number of cases.

There are many opinions, but not much hard data upon which to base infiltration requirements that are generally cost-effective. Current information indicates that about 200 gal/mi/in-dia/day (185.2 l/km/cm-dia/day) can normally be achieved in manhole to manhole tests with minimum to no effect on construction cost.

The magnitude of 200 gal/mi/in-dia/day (185.2 l/km/cm-dia/day) when testing a normal manhole to manhole length of 300 ft (91.4 m) should be kept in mind. The flow to be measured at this allowable infiltration rate for a 6 in. (15.2 cm) pipe will be 0.05 gal/min (0.19 l/min). Thus standard weirs will not generally be effective in measuring the flow.

A 200 gal/mi/in-dia/day (185.2 l/km/cm-dia/day) infiltration specification is appropriate for manhole to manhole testing, including manhole sections where the groundwater is at least 2 ft (61 cm) over the crown of the pipe, but not over 6 ft (1.8 m) in highly permeable soil. Tighter specifications may tend to increase the cost of construction in excess of the operating savings achieved.

Infiltration allowance for the pipe should reflect a consideration of the permeability of the soil, particularly the envelope around the pipe, in addition to the depth of groundwater over the pipe. This is true because relatively fine grained soils such as clays and silts have a tendency to partially relieve the effective external head acting on the pipe and, at the same time, soil particles tend to partially obstruct small defects in the pipe or joints, thus restricting the flow which would occur if only clean water were involved. Highly permeable soils, e.g., those containing large percentages of sand or gravel, do not produce these effects, and permit the full hydrostatic head to act directly on the pipe with no flow restrictions at potential defects. For this reason, when the native soil and envelope around the pipe is highly permeable, an increase in the infiltration allowance should be provided for, if the average groundwater head exceeds 6 ft (1.8 m). In these instances, it is recommended that the allowable infiltration be increased in proportion to the ratio of the square root of the actual groundwater head to the square root of the assumed base head of 6 ft. (1.8 m). For example, with permeable soil and an average groundwater head of 12 ft (3.7 m), the 200 gal/mi/in-dia/day (185.2 l/km/cm-dia/day) infiltration allowance should be increased to:

$$200 \times \frac{\sqrt{12}}{\sqrt{6}} \text{ or } 282 \text{ gal/mi/in-dia/day } (261.1 \text{ l/km/cm-dia/day}).$$

Many test sections in a system can be expected to show very little leakage. The average in a project after all test sections have been repaired to conform with infiltration limits should always be substantially less than the maximum allowed per test section. Since it is the average project infiltration that bears on treatment and pumping costs, it may be appropriate to apply a limit to average project infiltration which may be two-thirds or less of the allowance per test section. Otherwise, defects would be permitted to remain that should be corrected to insure the soundness of the system with respect to root growth and other maintenance problems.

Exfiltration--

Exfiltration limits to achieve similar control of infiltration should be set somewhat higher than the infiltration limits, since the specified net test head provides a fully effective hydrostatic pressure of the pipe joints which is not likely to be the case for infiltration testing. In addition, the movement of water out of a pipe is likely to be less impeded than the movement of soil-fines laden groundwater into the small defects which these tests are intended to detect. Accordingly, the combined leakage from the pipe and manholes could be fixed at about 200 gal/in.-mi/day (185 l/cm-km/day) when the average head on the test section is 3 ft (0.9 m). For other head conditions the leakage allowance should be adjusted in direct relationship to the ratio of the square root of the average test head to the square root of the base head (3 ft (0.9 m)). For example, with an average test head of 8 ft (2.4 m) the allowable exfiltration allowance should be:

$$200 \times \frac{\sqrt{8}}{\sqrt{3}} = 327 \text{ gal/mi/in.-dia/day (303 l/km/cm-dia/day)}$$

Manholes may be tested separately and independently. An allowance for manholes of 0.1 gal/hr/ft-dia/ft/head (0.04 l/hr/cm-diam/m/head) would be appropriate.

Low Pressure Air Testing--

Because of the cost and inconvenience of exfiltration testing with water, and problems associated with steep grades, air pockets in house lateral stubs, if used, and other factors, acceptance testing with low pressure air has come into widespread use. Leakage limits have been adopted which in general locate the same type of defects that are found by water testing; but, it should be understood that no direct mathematical correlation has been found applicable between air test limits and water exfiltration limits.

Air test allowance in use around the country generally follow, or are similar to, the criteria developed in California by Ramseier and Riek (3). These criteria were developed for wetted clay pipe and were found to be applicable to wetted concrete pipe through independent research by Duff in Seattle (4). The test has been widely and successfully used in testing smaller diameter pipe, but it is becoming apparent that modified criteria may be needed for sizes between 18 and 30 in. (45.72 and 76.2 cm). (Pipes larger than 30 in. (76.2 cm) are more conveniently accepted by use of individual joint testers).

Appendices B and C illustrate adaptations of the Ramseier-Riek criteria which in brief provide that when the tested line is at 3 psi (0.21 kg/cm^2) average gauge pressure, the rate of leakage shall not exceed 0.003 ft^3/min/ft^2 (9 x 102 l/min/m^2) of internal pipe surface, or 2 ft^3/min (0.94 l/sec) when the computed rate is less that 2 ft^3/min (0.94 l/sec).

In 1975, the American Society for Testing and Materials (ASTM) approved for the first time a tentative recommended practice, "Low-Pressure Air Test of Fortified Clay Pipe Sewer Lines 4 to 12 in. (10.16 to 30.48 cm)," designated C 828-75T. It contains much of the Ramseier-Riek criteria, including an allowable air loss of 0.003 ft ^{3}/min/ft ^{2}(9 x 10 ^{2} l/min/m ^{2})of internal pipe surface and a minimum of significant air loss per test section of 2 ft ^{3}/min (0.94 l/sec), but adds a new provision; the total allowable air loss shall not exceed 3.5 ft ^{3}/min (1.64 l/sec) in any test section. Procedures and a table of holding times based on the equations from ASTM C 828, are shown in Appendix C. Holding times have been expanded to include pipe through 24 in. (60.96 cm) diameter and are applicable to vitrified clay pipe.

Plastic, asbestos cement, and other non-air permeable pipe should be subjected to criteria more appropriate to those materials. Concrete and clay pipe, if saturated, is essentially non-air permeable and should be tested accordingly.

There is currently no general agreement as to what criteria are appropriate (for non-air permeable pipe) but these references indicate something in the range of 3 to 4 times the time required for pressure drop in air permeable pipe.

Although air test results do not relate directly to alternate water test criteria, and although criteria for testing are not yet firmly established, there is no question that the method has resulted in significant improvement in sewer construction, if only because the cost and convenience advantages have made it practical to test much more footage of installed pipe than had been tested with water.

Large Pipe

Pipe that is large enough to permit personnel to conduct interior inspections can be accepted on the basis of such inspection, plus testing of individual joints. A typical joint testing device isolates the joint, fills pipe with air or water and is pressurized. The rate of loss is then measured. Allowable leakage is usually the computed rate per foot of pipe times the distance between joints. In practice, however, it is a go or no-go test. The joint is generally either essentially bottle-tight or it leaks badly enough to require repair.

As a go/no-go test, air may be used directly in individual joint testing. A very slow drop of a needle indicates a good joint, and a rapid drop indicates a defective joint. However, testing conditions are very different when lines are tested and the Ramseier-Riek or other criteria cannot be used to derive timed pressure-drop criteria for a joint test.

It should be recognized that any of these criteria, properly enforced, will result in high quality construction and the difference in actual infiltration, resulting from use of one limit rather than another, should be relatively small.

Appendix C has been adapted from the Indiana State Board of Health draft regulations on methodology for leakage testing.

Obstruction-Proof Testing

Following the placement and consolidation of backfill and prior to the placement of permanent ground cover and/or roadway resurfacing, a test should be made to ascertain freedom from obstructions such as excessive pipe vertical ring deflections, joint offsets, lateral pipe protrusions into the sewer main, and accumulated debris.

All material, equipment and labor to perform such testing should be provided by the construction contractor. Testing equipment, systems and procedures should be in accordance with the direction of, and used only after approval of, the engineer.

Obstructions should be removed and all other conditions should not exceed five percent of the nominal inside diameter of the pipe being tested. Soil consolidation rates depend on variable conditions such as soil characteristics, moisture content, compaction procedures, depth of trench cover, and rate of installation. Because of these time dependent variables, it is advisable that obstruction-proof testing be one of the final acceptance criteria for the completed project. A suggested minimum time lapse following installation might be six months, although soil settlement may continue more than one year.

Either mandrels, solid cylinders, or balls with diameters of 95 percent of the specified pipe diameter may be used to test for obstructions.

Deflection Testing of Flexible Sewer Pipe

While many factors will influence the extent of deflection of an installed flexible sewer pipe, a major factor is the soil density on the sides of the pipe. Thus, a test for excessive deflection after completion of installation work provides for a simple way for checking the quality of the installation of flexible pipe. Testing may be accomplished by pulling a go/no go mandrel, sphere or other device through the pipe. To permit the pipe/soil system to attain initial 'equilibrium,' testing for initial deflection is generally not done sooner than 30 days after final backfilling and compaction.

At times, only a few selected portions of the system may be tested. More extensive, or even complete system testing may be called for depending on initial results. Deflection testing is sometimes not required when upon the judgement of the design engineer the combination of pipe properties, installation procedures, loading conditions and job inspection procedures ensure compliance to the set requirements.

The maximum allowable initial pipe deflection is set by the designer, in consideration of:

- Initial pipe roundness;
- Pipe stiffness;
- Anticipated pipe loading;
- Pipe installation technique including soil, compaction, etc.;
- Small amount of additional deflection that may continue before final stabilization of the pipe soil/system; and
- Safe ultimate deflection for the particular pipe specified.

Maximum specified allowable initial deflection values range from under 5 percent to as high as 10 percent of the initial theoretical round pipe diameter. Largely based on experience with flexible metal pipes, 5 percent has been accepted as the limitation for initial deflection for many plastic piping products.

For flexible products such as PVC sewer gravity piping which are capable of large ultimate deflections without structural damage some designers and authorities permit somewhat more liberal requirements. A few states permit up to 7 percent initial deflection and one is known to allow as high as 10 percent. In other states, authorities and engineers will specify 5 percent but relate it to the pipe's initial vertical non-deflected diameter which, in effect, because flexible pipes tend to be slightly out-of-round when unloaded, can be roughly equivalent to as much as 7 percent relative to the diameter of perfectly round pipe.

Any section of pipe that is found to exceed deflection requirements is corrected, or replaced, depending on pipe materials.

The ASTM recently surveyed users and specifiers of flexible pipe and found almost 90 percent of those who replied specified 5 percent or less, and that 10 percent was the maximum deflection being specified by those surveyed.

Inspection of Construction

The importance of adequate inspection during construction cannot be overemphasized. Material, time and money usually can be saved by supplying a fully trained inspector for all phases of sewer construction projects. Deliberate malpractices and unintentional mistakes can result in contravention of the designer's intent and jurisdiction's desire to provide a sewer system of dependability and long life.

An alert inspector pays dividends by requiring strict adherence to job standards, but he should not assume so active a role in the project that he preempts the supervisory direction of the contractor. If the contractor does not have adequate supervision on the job, the inspector should report this to the contracting authority and the project should be suspended until such supervisory personnel are available. The inspector and the field engineer logically may be asked to interpret specifications, but they cannot assume direction of, or responsibility for, the contractor's forces. If too many questions arise about the plans and specifications, the design engineer should visit the site and reassess the adequacy of these documents. The need for this type of job contact affirms the need for the design engineers, whether employed by the jurisdiction or by a consulting engineering firm, to keep in touch with the project during construction. The inspector should not be expected to make engineering design decisions.

The inspector should have basic responsibilities for adherence to specifications, the accounting or verification of quantities of material supplied, and time spent on the project. He should be provided with a log book and whatever other forms are necessary to produce an adequate record of all activities of the contractor's forces. He should observe and record weather conditions and all other occurrences and conditions that affect the quality of workmanship. It is not necessary that the inspector be a licensed professional engineer, but he should report to a professional engineer who should appear on the job frequently enough to answer all questions of the inspector or contractor. The consulting engineer or the municipal design engineer should recognize that construction is the ultimate realization of his plans. He should be well represented during this crucial period.

During the course of interviews the best inspectors were often described as retired contractors or former job superintendents who provide maximum practical experience and knowledge. They are familiar with all of the "tricks of the trade," both good and bad. They speak the language of the workers and engender respect because they know what they are talking about.

Testing for Acceptance

Acceptance testing and inspection are at times confused and considered to overlap; however, it should be made very clear that these are two separate quality control functions. Each may depend on the other but neither can substitute for the other. Although many engineers depend on criteria other than resistance to leakage as controlling factors in the design and construction of sewers, the chief method of guaranteeing a properly installed and workman-like job has been the use of leakage tests as a basis of acceptance.

The job specification should clearly indicate the party (owner or contractor) responsible for performance of the tests, the time schedule, and the manner and method of payment if testing is to be done by the contractor. All acceptance testing should be done under the supervision and responsibility of the project engineer.

Although contractors may choose to conduct leakage tests before backfilling, for their own assurance, it is very important that the actual acceptance testing be delayed until after backfilling and compaction has been completed. Many if not most of the defects which become sources of leakage and other problems are caused by loading imposed during backfill and compaction.

Infiltration Testing

If conditions suitable for direct measurement of infiltration exist, measurement is usually accomplished by blocking off the inflowing lines at the upper manhole and damming the pipeline at the inlet to the lower manhole. Because leakage allowances are very small, measurements are best made by timing the filling of a small container of known volume, or by directing flow into a plastic bag for a specified time, then measuring the content. A sheet metal dam with a spout can be readily devised and sealed in position with any convenient mastic material.

Except where manholes are very closely spaced, measurement should not be attempted on runs longer than manhole to manhole. Otherwise, defects that ought to be found and corrected may be missed because their effect is masked by an acceptable over-all leakage rate.

Exfiltration Testing

Exfiltration testing consists of filling the test section with water, pressurizing by filling the upstream manhole or a standpipe with water, and then, after allowing time for absorption into the manhole or pipe walls, measuring the rate of loss. The upstream manhole may serve as the standpipe, in which case the manhole leakage is measured together with the pipe leakage. Or, the standpipe may be a small diameter pipe with a container of a gallon or so capacity at the top in order that leakage during the timed period will occur without significant loss of head. When this procedure is followed, manholes should be tested separately. Their contribution to total infiltration can be signficant.

As with infiltration testing, test sections should be limited to manhole-to-manhole, to avoid missing unacceptable defects. The length of the test section may also be limited by maximum acceptable head at the lower end, typically fixed at 15 to 20 ft (4.6 to 6.1 m). The test head at the upper end should be at least 2 ft (61 cm) above the top of the pipe, or above existing groundwater level, whichever is higher, and should not be less than the maximum probable in-service groundwater head.

Provision should be made for bleeding off the air that may be trapped in plugged service lateral stubs. If trapped air is not removed, its leakage through defects or through the walls of air permeable pipe will result in a false measurement.

A disadvantage of testing by exfiltration lies in the problem of finding the necessary water and then disposing of it. Furthermore, when a serious defect exists, the amount of water leaked into the trench may complicate the dig-up and repair.

Air Testing

Low pressure air testing may be accomplished by measuring the rate of air inflow required to hold the test section at a uniform pressure, or by timing the rate of pressure drop in the test section. The timed pressure drop procedure requires less sophisticated equipment and is in most common use. A description of the equipment required, and a detailed step by step test procedure is given in Appendix B.

Criteria is commonly given in terms of rate of air loss at a uniform pressure. In adapting to the timed pressure drop procedure, it is customary to assume that a 1 lb (0.45 kg) drop, from 0.5 lb (0.27 kg) above the specified test pressure to 0.5 lb (0.27 kg) below, provides a comparable average pressure condition. The volume of atmospheric air that would be lost during a 1 lb (0.45 kg) drop in pressure would be $\frac{1}{14.7}$ times the volume of the test section. This volume, divided by the prescribed maximum rate, would be the minimum time required.

For example, if the criteria calls for a maximum rate of loss (R) of 3.5 cfm (0.1 m^3/min) at 3 psi (0.2 kg/cm^2) pressure, and the test section comprises 300 ft (91 m) of 12 in. (30 cm) and 200 ft (61 m) of 6 in. (15 cm) the minimum time would be computed as follows:

$$V = \frac{1}{14.7} \times L \times A = \frac{1}{14.7} \times 300 \text{ ft} \times \pi \times 0.5^2 \text{ ft} = 18.7 \text{ ft}^3$$

$$R = 3.5 \text{ ft}^3/\text{min}$$

$$T = \frac{V}{R} = \frac{18.7 \text{ ft}^3}{3.5 \text{ ft}^3/\text{min}} = 5.34 \text{ minutes}$$

Where: V = Volume to be filled; R = Rate of loss of air; and T = Time.

If a head of groundwater exists above the pipeline section to be tested, the air test pressure must be increased an offsetting amount. However, if any service connections included in the test extend above groundwater, it must be recognized that these portions of the test will be subjected to the full gage pressure. This will affect the rate of leakage and may result in a false measurement. Such increased pressure also increases the already substantial hazard of plugs blowing out. PLUGS SHOULD BE CAREFULLY BLOCKED. WORKMEN MUST BE KEPT OUT OF THE MANHOLES WHILE THE SYSTEM IS UNDER PRESSURE.

Manhole Testing

No practical means has been found for air testing of manholes. They must be tested separately when the lines are accepted on the basis of air testing. Manholes may also be tested separately when exfiltration tests are used to determine acceptability of the sewer lines. The procedure is inconvenient but not complicated: plugs must be inserted in all the connecting pipes (which must later be removed under water). The manhole is then filled to the required test depth which should be to at least the elevation of probable highest groundwater level. After a suitable time for normal absorption the manhole is refilled to the test level. Then timing is begun and at the end of a measured time period the amount of water required to refill the manhole to the test level is measured.

Still Photography

Photography, including colorslides, stereo-photos, etc., can provide a record of the condition of new sewer lines. Its use is primarily for new construction since line conditions generally allow an adequate view of defects as is true with TV inspection. It serves as an aid to the inspector by providing a record of sewer construction workmanship. It may reveal faulty joints or broken pipe.

TV Inspection

Television inspection is a method for observing the condition of the interior of sewer pipe. For new pipes, television detects cracks and other defects not detected by other means of observation or testing because the defect had been packed with clay during backfilling. Efforts have been made with some success to estimate actual infiltration flows observed in television studies. TV is also useful in the detection and eventual correction of infiltration problems in existing sewer systems. After building sewers have been connected, and the sewer is in use, infiltration, exfiltration, and air testing cannot be used. TV appears to have the following advantages:

a. Instantaneous viewing is possible. If a sewer line, new or old, cannot be viewed, this is immediately discernable. Where lines are restricted, causing sand or other debris to cover the lens of the camera, flooded dips in the lines, misalignments, and other such deficiencies can be determined immediately.

b. "Development of Pictures" is not necessary. Therefore, there is no delay in making a decision especially where time is of essence.

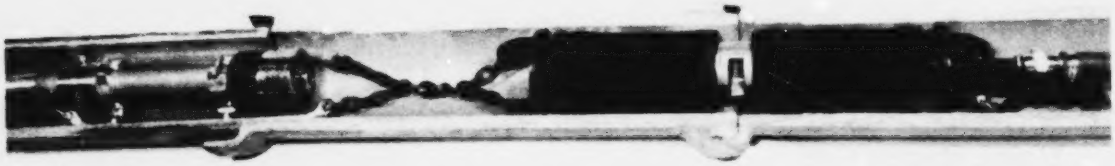
c. Several people can "view the line" together on the spot. In addition it is possible to take video recordings off the screen in order that permanent records can be made. Sound records onto the video tape are made at the time of recording to specifically identify the place, the time, and the conditions found. This saves unnecessary narration or eliminates later questions as to defect location or conditions. Instant or 35mm camera pictures may also be made of the TV picture as a permanent record.

d. With the use of TV it is possible to limit picture records to specific defects and those areas that typify the general condition of pipe free from defects.

e. TV provides the only means by which moving water can be observed. In addition, water of infiltration from house services that are noted to be running can be properly evaluated by TV viewing. When a house service is noted as running, a check of the building itself is possible to determine whether the flow is, in fact, domestic flow or water of infiltration.

TV has certain disadvantages:

1. Equipment operation requires operators with a good overall mechanical and electrical knowledge.
2. Evaluation of TV reports, especially in the case of infiltration studies, requires the services of a skilled or specialized professional engineer if optimum results of the study are to be achieved. Figure 22 shows a typical unit.



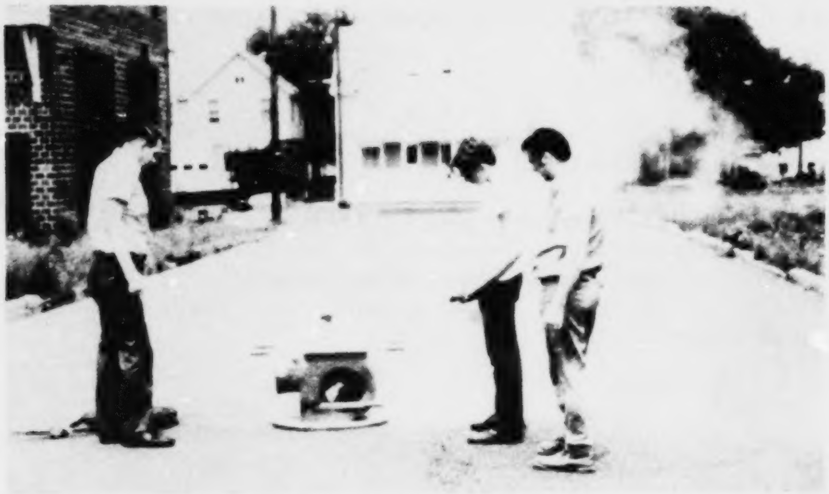
Source: Cherne Industrial, Inc.

Figure 22. Typical TV camera with packer unit.

Smoke Testing

Smoke is not an acceptable method of detecting all infiltration points. However, it has been extensively used to locate sewer cracks, defective joints and direct connection of a sanitary sewer to a storm sewer. In such cases, a smoke generating unit is placed in a manhole with a blower, and the smoke can be observed coming out of the soil wherever there is a leak. Driving a rod through soil near points of suspected leakage has been found useful in providing a passage for concentrated smoke discharge to the surface.

It would appear to be a method that has limited application on lines that are seriously damaged or have been installed very poorly. Smoke tests are useful in locating sources of inflow waters which enter sewer systems through pipe connections which are not trapped such as roof downspouts. Where a high-water table is present, the smoke will be absorbed by the overlying water. A blower set up over a manhole is shown in Figure 23. The number of sources determined is directly affected by the procedure used. Slight technique changes may change the number of sources found by a factor of 3 to 8.



Source: Superior Signal Company, Inc., Spotswood, New Jersey

Figure 23. Smoke testing blower set-up over manhole.

Visual Observations

In large size sewer lines, and also by the use of certain types of mirrors and lights i smaller sewers, it is possible to inspect visually certain pipe lines. Except in the case of large size pipe it would appear that other methods of inspection are more productive. In any case, this is not a quantitative test of sewer conditions.

Conditions for Acceptance Tests

Another aspect of testing is the final acceptance of a sewer line after construction. It is almost a universally accepted fact, although not always so practiced, that new sewer construction should be tested and accepted in as short sections as feasible. It becomes extremely difficult to assign responsibility for correction of new sewer lines if building connections have been installed as standard tests cannot be used. In addition, the crucial role of the building sewer must be taken into consideration; the sewer contractor cannot be held liable for any inadequacies of plumbing contractors who usually lay at least part of the building connection line. If new sewer lines are tested for final acceptance section by section and before connections are made, the sewer contractor can be held responsible for excessive infiltration rates which are found and evaluated by effective methods of testing.

Corrective Measures

Testing prior to acceptance may indicate that sections of the system do not meet the required infiltration standards. The decision then must be made as to whether or not the defective sections must be excavated and replaced or repaired, or whether internal sealing will be allowed. Where the defects are not extensive, internal sealing generally will tighten up the pipe to meet specifications. Excavation, on the other hand, often results in the breaking of adjacent joints.

The feeling that an internally sealed pipe is "less than new" has led to the replacement of defective sections. However, a realistic evaluation of the costs, problems, and possible additional effects on the pipe may indicate that the project specifications should require or allow the contractor the option of such sealing for minor defects when in the opinion of the inspecting engineer there are no structual deficiencies in the barrel of the pipe. Internal pipe grouting can be a permanent solution if the technique is applied in accordance with engineering principles that consider the type of soil being grouted and the nature of the defects being evaluated.

Building Sewer Standards

Jurisdiction and Control--

Building service conduits often represent a vital gap in regulation and control. The portion of the building sewer between the structure and the property line constitutes one part of the connection, while the portion between the property line and the public sewer in the street line completes the connection. Reference is made to these two portions of building sewers because separate parts have been constructed and connected under the control and supervision of separate governmental agencies. The connection to the building plumbing and drain system that extends to the property line often is interpreted as an extension of the structure facilities and is ordinarily installed under plumbing or building code regulations with testing and approval by plumbing officials or building inspectors. The section of the building sewer between the property line and the street sewer, including the connection thereto, usually is installed under sewer rules and inspection; approval is by the public works or sewer officials.

One exception to this rule of split authority often occurs in the case of industrial waste connections. Because of the effect of such wastes on sewer structures and treatment facilities, the entire length of these building sewers may be supervised by sewer officials. This procedure gives them better control of such connections and the introduction of wastes, when ruled to be amenable to sewer transportation and treatment.

Building sewers play a vital role in the overall infiltration and inflow volumes carried by separate sanitary and combined sewer systems. This split in authority impedes total control over building sewer construction, testing and acceptance under present circumstances when unified action is most needed. Contributing to potential entry of infiltration into sewer systems are the following factors: a) relatively short lengths of house or other building sewer runs, b) the multiplicity of these lines in a given stretch of collection sewers in heavily built-up urban areas, and c) that each house sewer run has three possible physical connection points---at the building line, at the property line, and at the junction with the public sewer.

If possible, one control agency should be responsible and supervise the building sewer as a single source of infiltration.

Codes, Construction and Testing--

Regulations governing building sewers are often contained in building or plumbing codes. They represent a considerable range of interest and control. Many codes make no reference to foundation drain connections, although many make the distinction between the building sewer and the building storm sewer. A number of codes still permit various area drains to be connected to the building sewer.

Most plumbing codes permit a wide range of materials to be used, although some of the most recent ones are more restrictive. A few codes require the building sewer to be tested, usually by holding a 10 ft (3 m) head of water for 15 minutes with no allowable leakage. Air testing is mentioned as a test procedure, mainly on the interior system although the building sewer also can be tested. Smoke tests also can be used as the pipe lies in the trench before backfilling and connection to the lateral. Small defects are then readily apparent.

Because of the potential severity of the infiltration and inflow contribution of building sewers, they should be constructed of top quality, watertight materials with thorough inspection and testing. The physical connection to the street lateral sewer should be performed by the sewer agency or department crews after careful training and inspection.

REFERENCES

1. American Public Works Association Research Foundation, "Control of Infiltration and Inflow Into Sewer Systems," EPA Publication No. 11022, 121 pp, December, 1970.

2. American Society for Testing Materials - Standards: "Test for Density of Soil in Place by Sand Cone Method," D#1556, 1968; and "Test for Density of Soil in Place by the Rubber Ballon Method," D#2167, Committee D18, 1966.

3. Ramseier, Roy E., and Riek, George C., "Low Pressure Air Test for Sanitary Sewers," Journal of the Sanitary Engineering Division Proceeding of the American Society of Civil Engineers, #3883 SA-2, 29 pp, April, 1964.

4. Duff and Chase, Unpublished report given at the Pacific Northwest Pollution Control Association, 1965.

SECTION IV

APPENDICES

A. Description of Laboratory Test for Determination of Possible Inflow Through Manhole Cover Pickholes and Seat Surfaces - Source: Neenah Foundry, Inc.

B. Sample Air Testing Specification - Source: Low Pressure Air Test for Sanitary Sewers by Roy E. Ramseier and George C. Riek, from April 1965 issue "Journal of the Sanitary Engineering Division ASCE."

C. Sewer Leakage Test Guidelines - Source: Adapted from Draft Regulations, Indiana State Board of Health.

D. Patterned Interview Infiltration/Inflow Analysis - Source: Elson T. Killam Associates.

E. Manhole Inspection Check List - Source: Elson T. Killam Associates.

F. Standards for Selected Sewer Pipe and Appurtenances - Source: American Society for Testing and Materials (ASTM).

APPENDIX A

DESCRIPTION OF LABORATORY TEST FOR DETERMINATION OF POSSIBLE INFLOW THROUGH MANHOLE COVER PICKHOLES AND SEAT SURFACES

(Source: Neenah Foundry Company, Inc.)

Purpose:

With the current strong emphasis on matters of ecology, the controlling agencies such as EPA are moving for complete sewage treatment. Many times this requires the addition of new treatment facilities; however this investment might not be required to such a great extent if infiltration and inflow in sanitary sewers could be at least partially eliminated.

It has been known for some time that considerable amounts of water enter through manhole covers by way of open pickholes, bearing surfaces, and so forth. The amount of course has not been known. The purpose of this test was to determine how much water can enter a manhole cover through the surface under varying conditions.

Material Tested and Procedure:

Seven different cover types and bearing surfaces were involved and on each, three separate tests were conducted. Listed below are the types of covers tested and their corresponding bearing surfaces which have been identified with a type number.

Type of Cover	Description
1	R-1040 non-rocking, Type "B" Lid, with two open pickholes measuring 1.25 x 1.5 in. (3.2 cm x 3.8 cm).
2	R-1040 non-rocking, Type "B" Cover, with two concealed pickholes.
3	R-1040 Machined, Type "B" Lid, with two concealed pickholes.
4	R-1040 machined, Type "B" Lid, with two concealed pickholes and sealed to frame with flat rubber gasket measuring about 0.125 in. (0.3 cm).
5	R-1040 machined, Type "B" Lid, with two concealed pickholes and sealed to frame with liquid type gasket similar to roofing cement.
6	R-1040 machined, Type "B" Lid, with two concealed pickholes and sealed to frame with "O" ring gasket.
7	R-1040 non-rocking type lid with an unmachined bearing surface and a 0.25 in. (0.6 cm) diameter Neoprene gasket

inlayed in the manhole lid.

All or some of the above covers were tested under four different conditions which will be described as conditions A, B, C, or D.

Condition A

Water was injected into the testing tank so that it rose above the top of the frame by about 0.063 in. (0.2 cm) and thereby covered the lid and flowed through the pickhole and through the bearing surface simulating a surface type drainage.

Condition B

Described as top surface drainage and accomplished by spilling water through the inlet pipe directly on the top of the cover similar to a heavy rainfall on the cover itself. This test varied from the "A" condition in that Test "A" had water introduced into the tank on the outside of the frame.

Condition C

Cover inundated with 1 in. (2.54 cm) head. The tank was filled so water covered the lid by 1 in. (2.54 cm) creating some additional flow pressure.

Condition D

5.5 in. (14 cm) head allowed to run down to zero.

Results

The test results by cover and type of test are shown in Table A-1. Values are shown in gallons per minute. In cases where the term "insignificant" is written, an almost immeasurable amount of leakage occurred. On tests where the reference "no test" is shown, it was felt that a test under these conditions was not necessary.

In addition one other test was conducted using a R-1040 Type "B", machined lid with two concealed pickholes and a flat rubber gasket. This was tested with a 3.5 in. (8.9 cm) head receding for 60 seconds resulting in leakage of 4 gal (15.1 l) per minute. It was discovered, however, a leak had occurred between the frame and the gasket seal in the tank which made the test inaccurate.

Conclusions

Tests definitely prove that the type of cover and pickhole determine the amount of inflow. By using different sealing methods such as flat or "O" ring gaskets or even sealing compound, space between cover and frame can be made almost watertight without bolting or other pressure devices normally used on watertight manhole castings.

TABLE A-1

TEST RESULTS

TYPE OF TEST

Type Cover	A		B		C		D	
	gal/min	ℓ/min	gal/min	ℓ/min	gal/min	ℓ/min	gal/min	ℓ/min
1.	6.31	23.9	7.4	28.0	27.3	103.3	60 to 85	227.1 - 321.7
2.	5.26	19.9	3.9	14.8	27.3	103.3	NO TEST	
3.	1.40	5.3	0.7	2.6	5.6	21.2	NO TEST	
4.	NO TEST		insignificant		insignificant		NO TEST	
5.	NO TEST		insignificant		insignificant		NO TEST	
6.	NO TEST		0.25	0.9	0.5	1.9	NO TEST	
7.	4.56	17.3	3.51	13.3	5.62	21.3	NO TEST	

APPENDIX B

SAMPLE AIR TESTING SPECIFICATION

(Source: Low Pressure Air Test for Sanitary Sewers by Roy E. Ramseier and George C. Riek, from April 1965 issue "Journal of the Sanitary Engineering Division ASCE).

It is recommended that the Specification for the Air Test consist of two parts: The Presumptive Test and the Acceptance Test.

The Presumptive Test

The contractor may low pressure air test the line before backfilling the trench to aid the contractor in checking the installation for any defects and proper workmanship. This test is at the option of the contractor.

The Acceptance Test

The contractor shall test the line as prescribed in the specifications by the engineer or agency after the backfilling has been completed.

Recommended Air Test

The contractor shall furnish all facilities and personnel for conducting the test under the observation of the engineers. The equipment and personnel shall be subject to the approval of the engineers. The contractor shall clean the line before proceeding with the air test. All debris shall be removed at the first manhole where its presence is noted. In the event cemented or wedged debris or a damaged pipe shall prevent cleaning, the contractor shall remove the obstruction. The pipe or sections of pipe to be tested should be wetted before the air test is started.

Immediately following the pipe cleaning and wettings the pipe shall be tested with low pressure air. Air shall be slowly supplied to the plugged pipe installation until the internal air pressure reaches 4.0 psi (0.28 kg/cm^2) greater than the average back pressure of any groundwater that may submerge the pipe. At least two minutes shall be allowed for temperature stabilization before proceeding further. The rate of air loss shall then be determined by measuring the time interval required for the internal pressure to decrease from 3.5 to 2.5 psi (0.24 to 0.18 kg/cm^2) greater than the average back pressure of any groundwater that may submerge the pipe.

The pipeline shall be considered acceptable when tested at an average pressure of 3.0 psi (0.21 kg/cm^2) greater than the average back pressure of any groundwater that may submerge the pipe when the section under test does not lose air at a rate greater than 0.003 ft^3/min/ft^2 (0.09 m^3/min/cm^2) of internal pipe area except that the minimum allowable rate of loss for the section shall not be less than 2 ft^3 (0.06 m^3) per minute.

The requirements of this specification shall be considered satisfied if, during the time as computed according to the attached page entitled "Recommended Procedure for Conducting Acceptance Test", the pressure in the pipe line does not drop more than 1 psi (0.07 kg/cm^2) below the initial pressure of 3.5 psi (0.24 kg/cm^2) greater than the average back pressure of any groundwater head that may submerge the (pipe) line.

The acceptance test shall be made for each first section of line constructed, for every first reach of line installed where a new sewer crew is used, or wherever the engineer may direct. The contractor shall not preceed with any construction until the prerequisite of meeting the successful installation of each section is made, as mentioned above, to qualify the crew and/or material.

If the pipe installation fails to meet these requirements, the contractor shall determine at his own expense the source or sources of leakage, and he shall repair or replace all defective materials or workmanship. The completed pipe installation shall meet the requirements of this test, or the alternate water exfiltration or infiltration test before being considered acceptable.

Safety Provisions

The plugs must be firmly secured and care should be exercised in their removal. The total force on a 12 in. (30.5 cm) plug at 4.0 psi (0.28 kg/cm^2) is over 450 lbs (204 kg). Care must be exercised in not loading the sewer line with the full pressure of the compressor. Keep men out of manholes until the pressure has been released. If water leaks into the line after the plugs are installed and floods the air inlet and the needle on the air pressure indicates zero then possibly the water column has balanced the air pressure in this instance and care is necessary in releasing the pressure. If testing below ground water level; inject the air at the upper plug and/or turn the inlet up as with a water test apparatus.

RECOMMENDED PROCEDURE FOR CONDUCTING ACCEPTANCE TEST

1. Clean pipe to be tested by propelling snug fitting inflated rubber ball through the pipe with water.

2. Plug all pipe outlets with suitable test plugs. Brace each plug securely.

3. If the pipe to be tested is submerged in groundwater, insert a pipe probe by boring or jetting, into the backfill material adjacent to the center of the pipe and determine the pressure in the probe when air passes slowly through it. This is the back pressure due to groundwater submergence over the end of the probe. All gauge pressures in the test should be increased by this amount.

4. Add air slowly to the portion of the pipe installation under test until the internal air pressure is raised to 4.0 psig.

5. Check exposed pipe and plugs for abnormal leakage by coating with a soap solution. If any failures are observed, bleed off air and make necessary repairs.

6. After an internal pressure of 4.0 psig is obtained, allow at least two minutes for air temperature to stabilize, adding only the amount of air required to maintain pressure.

7. After the two minute period, disconnect air supply.

8. When pressure decreases to 3.5 psig, start stopwatch. Determine the time in seconds that is required for the internal air pressure to reach 2.5 psig. This time interval should then be compared with the time required by specification as computed below.

9. List size and length of all portions of pipe under test in table similar to one shown here.

Diameter inches	Length feet	$K = .011\ d^2L$	$C = .0003882\ dL$

Total K________ Total C __________

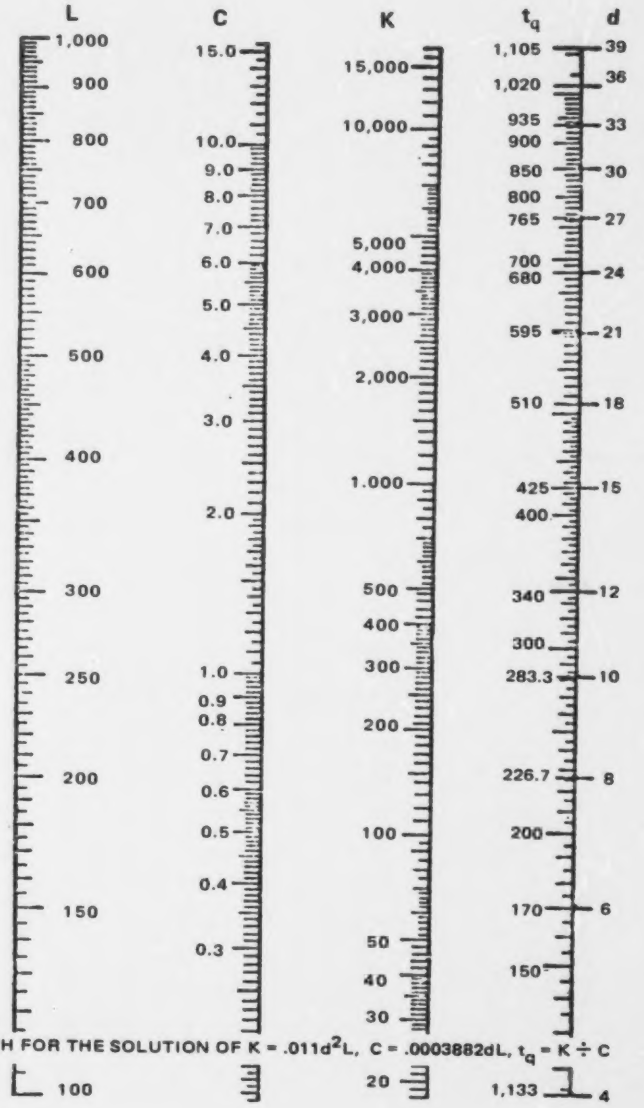
Time required by specification________

10. By use of nomograph, compute K and C. Use scales d and L, read K and C, and enter these values in the table above.

11. Add all values of K and all values of C for pipe under test.

12. If the total of all C values is less than one, enter the total of all K values into the space for "Time Required by Specification."

13. If the total of all C values is greater than one, divide the total of all K values, by the total of all C values, to get t_q. To make this division with the nomograph, use scales C and K, and read t_q.



NOMOGRAPH FOR THE SOLUTION OF $K = .011d^2L$, $C = .0003882dL$, $t_q = K \div C$

APPENDIX C

SEWER LEAKAGE TEST GUIDELINES

(Adapted from Draft Regulations Indiana State Board of Health)

Presented herein are recommended methods for conducting water leakage tests of sanitary sewers by the infiltration/exfiltration test and by the low-pressure air test.

INTRODUCTION

There are three methods of sewer test methods, and the choice of method is mainly dependent on the groundwater conditions surrounding the section of sewer to be tested. In the following discussion, the method for determining the groundwater table (GWT) and the choice of sewer leakage test method will be described. In addition, the recommended method for performance of a leakage test on system manholes is described.

Procedure for Determination of Groundwater Level

Groundwater table should be measured either at a manhole or at a pipe section between two manholes:

GWT measurement at a Manhole--

In areas where a high groundwater table is known to exist the contractor shall install, during the sewer construction, a 0.5 in. (1.27 cm) diameter capped pipe nipple, approximately 10 in. (25.4 cm) long, through the manhole along the top of the sewer. If this length of pipe is not installed during construction, the contractor will drill a hole through the manhole to permit installation of this pipe. Immediately prior to performance of the Leakage Test:

a. Remove the pipe nipple cap.

b. Blow air through the 10 in. (25.4 cm) length of pipe with sufficient pressure to clear the line.

c. Connect a clear plastic tube to the pipe nipple and raise it vertically along the manhole wall.

d. After the water has stopped rising in the tube, the height in feet of water over the crown of the pipe shall be taken.

GWT Measurement at a Pipe Section--

Insert a pipe probe, by boring or jetting into the backfill material adjacent to the center of the pipe at the midpoint of the sewer section under test and determine the pressure in the probe when air passes slowly through it. The pressure value, expressed in psi should be multiplied by 2.31 to determine that static head of water over the pipe.

Selecting Leakage Test Method

In the presence of groundwater the following condition will decide which test should be conducted.

The infiltration test will apply only where the groundwater table is above the crown of the pipe by a minimum head of 2 ft (61 cm). (This measured head must be existing at the highest point of the section of sewer line under evaluation.) If the groundwater table is above the crown of the sewer under test, an exfiltration test is not recommended. However, if a means of providing net positive head of more than 2 ft (61 cm) of head is possible, an exfiltration test can be conducted.

A low-pressure air test is applicable under all conditions of groundwater levels surrounding the sewer. In cases where the groundwater table is above the crown of the pipe, the air pressure can be increased by an increment equal to the pressure exerted by the groundwater over the pipe (e.g. 1 ft (30.5 cm) of water is equivalent to 0.434 psi (0.03 kg/cm^2)). All section of sewers shall be tested.

Detailed specifications must be included with project submittal to the State Board of Health for review, outlining the methodology for performance of sewer system testing.

Testing of System Manholes for Water Tightness

All manholes in the system shall be tested for water tightness by plugging the inlet and outlet sewers with tight plugs, filling the manhole with water and allowing one hour for saturation of manhole material. After one hour, the manhole shall be refilled to the original level. After two hours, the difference in water surface elevation from original to final level shall be measured and converted into gallons per hour lost through manhole leakage. The allowable leakage in system manholes shall be 3.0 gal (11.4 l) per hour. (Based on the established criteria for sewer system leakage of 200 gal/in.-dia/mi/day (185.2 l/cm-dia/km/day) an equivalent limitation for infiltration/exfiltration in system manholes was derived. Since the leakage entering or leaving a sewer system is related to the number of pipe joints in the system, the allowable leakage rate for manholes, 3.0 gal/hr (11.4 l/hr) was determined on an equivalent basis using the number of joints in a standard manhole).

An exfiltration test shall be conducted in accordance with the above description unless the groundwater table is at or above a level one-half the depth of the manhole. In this rare case an infiltration test will be conducted by including the manhole in the section of sewer to undergo test. In other words, the allowable infiltration for a section of sewer which is below the groundwater table to such an extent that the upstream manhole is also more than half submerged shall be tested by installing the water tight plug in the influent sewer line to the manhole and including the allowable infiltration from the manhole with the amount calculated for the sewer system.

Field data shall be recorded on Form A, Manhole Leakage Test Data, and submitted for approval.

PROCEDURE FOR CONDUCTING AN INFILTRATION TEST

Clean the pipe section (manhole to manhole reach of sewer) being tested by propelling a snug-fitting inflated ball, or other adequate method, through the pipe with water.

Determine the groundwater table (GWT). (See procedure above). The GWT shall be noted for the section of line undergoing test and included with the test results submitted to the State Board of Health for each section of line tested.

Plug the upstream pipe outlet from the manhole with a plug which will assure a tight seal against flow from upstream portions of the sewer system. To assure a tight seal, the plug shall be at least a length equal to the diameter of the pipe section undergoing test.

Install a weir in downstream manhole of section undergoing test. The following discussion is intended to provide the contractor and engineer with established criteria for placement and accurate reading of the weir.

a. The type of weir used shall be noted. Weirs are classified according to the shape of the notch (i.e. rectangle, trapazoid or triangular most often called V-notch).

b. Since the most common weir employed for sewer testing is a 90° V-notch weir, procedures and items will be outlined affecting a valid test. If another weir type is to be used, the engineer must submit similar information in the project specifications.

c. Weir must be installed in its proper position; plumb and tight to the pipe wall surface.

d. A definite period of time shall be included in the specifications denoting the allowance for infiltrated waters to crest the weir. A one hour period is recommended for sufficient

FORM A - MANHOLE LEAKAGE TEST DATA

1. Municipality: ______________________________
2. Project Inspector: ______________________________
3. Date of Test: ______________________________
4. Location of the Manhole: ______________________________
5. Depth of Manhole from Ground: __________ feet __________ inch
6. Size(s) of pipe(s) connected: ______________________________
7. Groundwater table (GWT) measurements:
   a. Method Used: ______________________________
   b. GWT elevation: __________ feet from the top of the manhole
8. Water level after filling the manhole _____ feet _____ inch from top

   at the beginning _____ feet _____ inch from top

   at the end _____ feet _____ inch from top

   time elapsed _____ hour(s)
9. Diameter of the manhole where the water level was measured:

   __________ feet __________ inch
10. Total volume lost: __________ gallons
11. Leakage Rate: ______________ gallons/hour/manhole
12. Manhole: pass ☐ fail ☐

water to build up behind the weir with the eventual overflow or cresting of weir, at a constant rate.

e. The head (H) of water flowing over the weir must be measured accurately and the measurement taken at least 18 in. (46 cm) upstream from the crest of the weir or three times the height of H, whichever is greater.

f. Discharge over the 90° V-notch weir shall be calculated according to:

$$Q = 3240\ H^{2.5}:\ \text{H in inches, Q in gallons per day}$$

The infiltration test shall be performed by the contractor at his expense in the presence of the engineer, or his authorized agent, after completion of construction, backfilling, compaction and prior to placement of pavement.

g. When there is significantly more than two feet of groundwater table above the top of the pipe at the highest point in the section being tested, ten percent additional infiltration above the required 200 gal/in.-dia/mi/day (185.2 l/cm-dia/km/day) limit will be allowed for every 2 ft (61 cm) of additional head.

h. Field data shall be inserted on Form B. "Infiltration Test Data," for the infiltration test.

PROCEDURE FOR CONDUCTING AN EXFILTRATION TEST

Prior to initiating an exfiltration test the level of groundwater adjacent to each section undergoing test must be determined. The exfiltration test works on the basis that a certain pressure will force water out of the line into the soil surrounding the pipe. If the groundwater level is above the crown of the pipe measured from the highest elevation of the sewer the infiltration test is the preferred test method.

Clean the pipe section (manhole to manhole reach of sewer) being tested by propelling a snug-fitting inflated ball, or other adequate method, through the pipe with water.

Plug the downstream pipe outlet to the manhole with a plug which will assure a tight seal against water leakage from the upstream water. To assure a watertight seal the plug shall be at least a length equal to the diameter of the pipe section undergoing test.

Exfiltration test is based on the loss of water from the section of sewer being tested; therefore, the method of imposing a specified pressure head on the system must be described. Also just as impor-

FORM B - INFILTRATION TEST DATA

1. Municipality: ____________________

2. Project Name: ____________________

3. Location of Sewer: ____________________

4. Weather conditions: ____________________

5. Test Start: __________ a.m. __________ p.m.

6. Pipe (was) (was not) cleaned by balling before test

7. Determination of groundwater table (GWT):

   below pipe invert   at pipe wall   above the crown

8. Describe how GWT was determined: ____________________

   ____

   ____

9. Sewer information: diameter __________ inches

   length __________ feet

10. Type weir used: ____________________

11. Time elapsed for infiltrated water to crest weir __________ min.

12. Head, H. measured __________ inches

13. Allowable infiltration for sewer section under test __________ gal

14. Actual loss calculated using $Q = 3240 H^{2.5}$ __________ gal

15. System: pass ☐ fail ☐

16. Signature of Inspector ____________________

    Date ____________________

tant, the volume of water necessary to impose this head must be restricted to a calculated volume for each portion of sewer. The allowable exfiltration is the same as specified for infiltration.

a. Methods for imposing pressure head on system

1. The upstream manhole may be used as a reservoir for maintaining the pressure head. The head of water shall be a minimum of 2 ft (61 cm) higher than the crown of the pipe at the high point in the line being tested or at least 2 ft (61 cm) above the existing groundwater table, whichever is greater. Ten percent additional exfiltration will be allowed for each 2 ft (61 cm) of water head above the minimum value for conducting an exfiltration test.

2. A standpipe may be used instead of the upstream manhole for providing the pressure head on the system. The head of water shall not be less than 2 ft (61 cm) nor greater than 15 ft (4.5 m) above the crown of the pipe measured from the highest point in the section under test. Use of the standpipe requires that the pipe be refilled to maintain a constant pressure head. The gallons added must be noted and reported as the actual exfiltration.

3. The ten percent additional loss shall also apply when the standpipe is used for providing the pressure head.

After plugging the downstream manhole securely as explained in procedure for conducting infiltration test, and after the method for placing the necessary pressure head on the system is decided, water may be added to fill the sewer and manhole or standpipe, whichever is utilized.

a. The amount of water (volume needed to fill the sewer plus the manhole or standpipe) shall be calculated for each reach of the system.

Water shall be introduced from the upstream manhole and shall be metered not to exceed the approximate volume calculated by the engineer to completely fill the sewer and manhole or standpipe.

This approximate volume of water should not be exceeded because the excess water introduced is obviously leaving the sewer through a leak or leaks and saturating the surrounding soil. Once the soil surrounding the section of sewer under test is saturated, less water will exfiltrate from the system and the test results will be invalid.

b. Water will be allowed to stand for a period long enough to allow water absorption in the pipe. For some materials up to six hours may be required depending upon the degree of saturation prior to testing. After the absorption period, the pipe shall be refilled to the established measuring mark and the test begun.

c. Determination of the actual exfiltration is based upon the method used for providing pressure head on the system, either by standpipe or the upstream manhole.

   1. Use of the standpipe requires that a constant water level be maintained in the standpipe to keep the specified pressure head on the sewer section under test. Therefore, the volume of water added to the standpipe over the one hour test period is the exfiltration from the section under test.

   2. When using the manhole, exfiltration will be determined by measuring the difference in original water elevation from the final water elevation and converting to actual gallons loss through the pipe after a one hour period.

d. If the line does not meet with the engineer's calculated permissible loss, the section of sewer shall be unacceptable. Another exfiltration test shall not be conducted until the groundwater conditions surrounding the pipe return to a condition similar to those existent at the beginning of the test period. The groundwater elevation shall be determined prior to initiation of the second test.

e. Field data shall be included on Form C "Exfiltration Test Data" for conduction of an exfiltration test.

PROCEDURE FOR CONDUCTING A LOW-PRESSURE AIR TEST

Clean pipe to be tested by propelling a snug fitting inflated ball through the pipe by water pressure or other adequate method. This step is important because it not only flushes out construction debris, but the water used to flush the ball through the pipe dampens the pipe wall. The rate of air loss through pipe wall permeation can be significant on dry pipes.

Plug all pipe outlets with pneumatic plugs having a sealing length equal to or greater than the diameter of the pipe to be tested. The pneumatic plug shall be able to resist internal testing pressures without requiring external bracing.

The groundwater level surrounding the section of sewer under testing shall be determined by one of the procedures previously out-

FORM C - EXFILTRATION TEST DATA

1. Municipality:____
2. Location of sewer:____
3. Weather conditions____
4. Test Start:__________a.m.-__________p.m.
5. Pipe (was) (was not) cleaned by balling before test.
6. Determination of groundwater table (GWT):

   below pipe invert   at pipe wall   above the crown
7. Describe how (GWT) was determined:__________________________
8. Sewer information:

   diameter________inches

   length__________feet

   volume__________cu ft, refer to exfiltration test discussion
9. Method used for imposing pressure head on system:

   upstream manhole

   standpipe
10. Saturation period of manhole and pipe:_________________________
11. Manhole used for imposing pressure head, complete following:

    Initial water surface elevation_______feet_______inch

    Pressure head on system_______psig

    End water surface elevation_______feet_______inch

    Elapsed time for test_______

    Diameter of manhole where water levels were measured_______

    Volume water loss_______gallons

    Actual exfiltration rate_______gpd/inch/mile
12. Standpipe used for imposing pressure head, complete following:

    Pressure head imposed on system_______feet_______inch

    Gallons added during test period_______

    Exfiltration rate_______gallons/inch-dia/mile/day
13. Decision of inspector: pass   fail

    Signature of inspector____________________________Date_______ lined in the introduction. If the groundwater table is above the pipe then test pressures shall be increased by the corresponding increment. (e.g. if the groundwater table is 1 ft (0.3 l) above the lowest crown of the pipe, the air pressure should be increased by 0.43 times each foot (0.3 l) of water.

Once the pipe outlet plugs are securely in place, pressurized air is introduced to the system. The air shall be fed through a single control panel with three individual hose connections as follows:

1. From control panel to pneumatic plugs for inflation in sewer pipe.
2. From control panel to sealed line for introducing the pressurized air.
3. From sealed line to control panel. This line will enable continous monitoring of the air pressure rise in the sealed line.

The air shall be introduced slowly to the section of pipe under evaluation until the internal air pressure is raised to 4.0 psig (0.28 kg/cm^2) greater than the hydrastatic pressure head created by the existence of groundwater that is over the pipe section.

A minimum of two minutes shall be provided for the air pressure to stabilize to conditions within the pipe. (This stabilization period is necessary for variations in temperatures to adjust to the interior pipe conditions). Air may be added slowly to maintain a pressure of 3.5 - 4.0 psig (0.24 - 0.28 kg/cm^2) for at least two minutes. During the temperature stabilization period the stopwatch should be made ready and the plugs, pipes, and hoses checked for proper seal by spraying with a soap solution.

After the stabilization period, when the pressure reaches exactly 3.5 psig (0.24 kg.cm^2) the stopwatch is started and when the pressure reaches 2.5 psig (0.28 kg/cm^2) it is stopped. If the time required for a one pound pressure drop 3.5 to 2.5 psig (0.24 to 0.28 kg/cm^2) is not less than the allowable (see Table C-1) time for the pipe section under test to lose air, the section shall pass the leakage test.

There are several methods for computation of allowable time for the low pressure air test; however, for ease of computation and establishment of stand time increments for varying diameter sewer pipes of saturated, air porous material, such as unglazed V.C. and concrete, the chart presented in Table C-1 is applicable. Field data shall be recorded in Form D, Air Test Data Sheet, for conducting a low-pressure air test.

TABLE C-1
MINIMUM HOLDING TIME IN SECONDS REQUIRED FOR PRESSURE TO DROP FROM 3.5 PSIG (0.24 KG/CM^2) to 2.5 PSIG (0.28 KG/CM^2)

Length of Pipe (Ft)	PIPE DIAMETER IN INCHES													
	4	6	8	10	12	15	18	21	24	27	30	33	36	39
25	4	10	18	28	40	62	89	121	158	200	248	299	354	418
50	9	20	35	55	79	126	178	243	317	401	495	599	713	837
75	13	30	53	83	119	186	267	364	475	601	743	898	1020	1105
100	18	40	70	110	158	248	356	485	634	765	851	935		
125	22	50	83	138	198	309	444	595	680					
150	26	59	106	165	238	371	510							
175	31	69	123	193	277	425								
200	35	79	141	220	317									
225	40	89	158	248	340									
250	46	99	176	275										
275	48	109	194	283										
300	53	119	211											
350	62	139	227											
400	70	158												
450	79	170												
500	88													
550	97													
600	106													
650	113	170	227	283	340	425	510	595	680	765	851	935	1020	1105

Source: Ramseier, Roy E., and Riek, George C., "Low Pressure Air Test for Sanitary Sewers." Journal of the Sanitary Engineering Division, ASCE, April 1964, 28 pp.

FORM D - AIR TEST DATA

1. Municipality:____

2. Location of Sewer:____________________________________

3. Project Name:____

4. Description of Pipe Installation Under Test
    diameter__________inches
    length___________feet

5. Field Conditions
    groundwater table level (GWT): below pipe ☐ above pipe ☐
        feet of head__________
    determination of GWT: from manhole ☐ pipe probe ☐
        other ☐ (describe procedure)

6. Time required for Pipe Section (length and diameter dimensions)
    Pressure Drop__________(seconds)

7. Field Test Data:
    date__________Time__________a.m.__________p.m.
    estimated temperature__________

8. Start Test: Initial pressure__________psig
        Pressure increase due to hydrastatic head ______psig
    Stop Test: end pressure__________psig
    Test shows loss of_______psig in_______seconds @ average
        pressure of________

9. System: pass ☐ fail ☐

10. Signature of Inspector___________________________________
        Date___________________________________

REPORTING OF LEAKAGE TEST RESULTS

As a condition of approval in all sewage works projects, the Indiana State Board of Health has recently requested submittal of test results on the completed sewer system. Test results shall include detailed information covering the items outlined herein. It will no longer be satisfactory to simply state that the sewer system did not exceed the 200 gal (757 l) limit and, therefore, conclude the system passes. Field test data will be required for all sections and manholes of the sanitary sewer. The project engineer will be responsible for completion and submittal of the tests conducted for the entire system.

Review of project specifications shall be made with special attention to compliance with the procedures outlined herein. The specifications shall indicate which method will be employed if several are discussed. In no case shall the contractor be permitted to change to another test if the original method reveals the system has failed. The section or sections failing to meet established standards shall be repaired by the contractor and retested according to the test procedure of the original test. Both sets of test data must be submitted to the Indiana State Board of Health.

APPENDIX D

PATTERNED INTERVIEW INFILTRATION/INFLOW ANALYSIS
(Source: Elson T. Killam Associates)

MUNICIPALITY:________________________ CLIENT:____________________

COUNTY:______________________________ PROJECT NO:________________

INTERVIEWEE:_________________________ DATE:______________________

INTERVIEWER:_______________

1. General Contacts:

Name:________________________________ Title:_____________________

Address:_____________________________ Tel. No:___________________

Other Contacts:

a. Maintenance:

Name:________________________________ Title:_____________________

Address:_____________________________ Tel. No:___________________

b. Records of Maintenance:

Name:________________________________ Title:_____________________

Address:_____________________________ Tel. No:___________________

c. Maps:

Name:________________________________ Title:_____________________

Address:_____________________________ Tel. No:___________________

d. Engineer:

Name:________________________________ Title:_____________________

Address:_____________________________ Tel. No:___________________

e. Health Officer:

Name : ____________________ Title: ____________________

Address: ____________________ Tel. No: ____________________

f. Building Inspector:

Name: ____________________ Title: ____________________

Address: ____________________ Tel. No: ____________________

g. Plumbing Inspector:

Name: ____________________ Title: ____________________

Address: ____________________ Tel.No: ____________________

h. Planning Board:

Name: ____________________ Title: ____________________

Address: ____________________ Tel No: ____________________

i. Potable Water Supplier:

Name: ____________________ Title: ____________________

Address: ____________________ Tel. No: ____________________

j. Chamber of Commerce:

Name: ____________________ Title: ____________________

Address: ____________________ Tel. No: ____________________

2. Municipal Offica1s:

	Name	Telephone Number
a.	Mayor: ____________________	____________
b.	Clerk: ____________________	____________
c.	City Engineer: ____________________	____________
d.	Public Works Dir: ____________________	____________
e.	Sewer Supt: ____________________	____________

f. Sanitary Treatment Plant

Supt. or Operator:_________________________ _______________

g. Others:_____________________________ _______________

_____________________________ _______________

3. Maintenance Department and Equipment:

Manpower: Foreman_________Laborers_________Operators_________

Equipment: Rodders______Jets______Eductors______Trucks______

Other Equipment:____

Type of Cleaning Program: Preventive________Emergency_________

Details:____

____

____

____

4. Maintenance Records:

Availability: Yes__________No__________

Period Covered by Records: From__________To__________

Type: Cards_________Map_________Notes_________Other_________

Remarks:____

____

____

5. Plans and Maps:

a. Storm Sewers:

Overall Scale_________Reproducible_________Date______________

Location Where Filed__________Date of Updating______________

b. Storm Interceptors:

Overall Scale__________Reproducible__________Date__________

Location Where Filed__________Date of Updating__________

c. Storm Laterals:

Overall Scale__________Reproducible__________Date__________

Location Where Filed__________Date of Updating__________

d. Street Maps:

Overall Scale__________Reproducible__________Date__________

Location Where Filed__________Date of Updating__________

e. Tax Maps:

Overall Scale__________Reproducible__________Date__________

Location Where Filed__________Date of Updating__________

f. Sanitary Sewers:

Over Scale__________Reproducible__________Date__________

Location Where Filed__________Date of Updating__________

g. Sanitary Interceptors:

Overall Scale__________Reproducible__________Date__________

Location Where Filed__________Date of Updating__________

h. Sanitary Laterals:

Overall Scale:__________Reproducible__________Date__________

Location Where Filed__________Date of Updating__________

6. Standard Sanitary Sewer Specifications Availability:

Yes__________None__________Attached__________

Remarks:______________________________

____

____

7. **Plumbing Codes:**

Yes________No________State Code Adopted_______Revised__________

Copy Attached________Remarks:________________________________

____

____

8. **Services:**

a. Inspection Riser: Started __________ (Date) Stopped __________ (Date)

Type of Material for Pipe & Pipe Joints: Present________________Date________

Past____________________Date________

c. Roof Leaders Allowed: Present________________Date________

Past____________________Date________

Elimination_____________Date________

Remarks______________________________

d. Sump Pump Connections: Present________________Date________

Past____________________Date________

Elimination_____________Date________

Remarks______________________________

e. Foundation Drains: Present________________Date________

Past____________________Date________

Eliminations____________Date________

Remarks______________________________

f. Connection Records: Available_______Yes_______No________

Period___________________To__________

Type: Cards__________Map___________

Notes__________Others______________

9. Types of Pipes in Services:

		% Seperate Sanitary	% Seperate Storm	% Combined	Type of Joints
a.	Asbestos-Cement				
b.	Cast Iron				
c.	Plastic				
d.	Reinforced Concrete				
e.	Steel				
f.	Vitrified Clay				
g.	Other				
	TOTAL				

10. Lengths of Sewers in Service (total in Miles):__________________

Miles of Sanitary_______Seperate Storm_______Combined_________

% Total Sanitary________% Total Storm________% Combined________

Linear Feet:____________Linear Feet:_________Linear Feet:______

Sewer Size	Sanitary	Storm	Combined	Total
8"				
10"				
12"				
15"				
18"				

Manholes:

Manhole Materials: Brick_____% Block_____% Precast__________%

Frame Catalog Numbers____

Details Attached? Yes__________No__________

11. **Maintenance or Operational Difficulties:**

What maintenance or operational difficulties have been experienced regarding the following (please locate affected areas by mark-up on appropriate map, and complete the questions listed below):

Records:

a. Local flooding of sewers, basement flooding, or back-up:

Who or what department investigated the problem:____________

____

What happened? List circumstances, nature, and extent of problem: ____

____

____

____

Where did problem occur? List location, type of area (residential, commercial, industrial, etc.): ____________________

____

____

When did problem occur? List date, duration, frequency of each occurrence, etc. ________________________________

____

____

____

What type of system was involved? List type of pipe material, age of pipe, type of joints, etc.:

Why and how did problem occur? State your opinion as to why and in what manner the problem occurred, or the difficulty that was encountered:

Supplementary information: Describe the ground conditions, water conditions, etc., in the area in question:

State what corrective action, if any, was (or should be) taken to correct the situation:

List any other information you may care to volunteer concerning the operational difficulty encountered:

Records:

b. Blockages:

Who or what department investigated the problem: ____________

____

What happened? List circumstances, nature, and extent of

problem: ________________________________

____

____

____

Where did problem occur? List location, type of area (residential, commercial, industrial, etc.):

____

____

When did problem occur? List date, duration, frequency of

each occurrence, etc: __________________________

____

____

What type of system was involved? List type of pipe material, age of pipe, type of joints, etc:

____

____

____

Why and how did problem occur? State your opinion as to why and in what manner the problem occurred, or the difficulty that was encountered:

____

____

____

Supplementary information: Describe the ground conditions, water conditions, etc., in the area in question:

State what corrective action, if any, was (or should be) taken to correct the situation:

List any other information you may care to volunteer concerning the operational difficuly encountered:

Records:

c. Excessive overflow from combined sewers:

Who or what department investigated the problem:

What happened? List circumstances, nature, and extent of problem:

Where did problem occur? List location, type of area (residential, commercial, industrial, etc.):

When did problem occur? List date, duration, frequency of each occurrence, etc:

What type of system was involved? List type of pipe material, age of pipe, type of joints, etc.:

Why and how did problem occur? State your opinion as to why and in what manner the problem occurred, or the difficuly that was encountered:

Supplementary information: Describe the ground conditions, water conditions, etc., in the area in question:

State what corrective action, if any, was (or should be) taken to correct the situation:

List any other information you may care to volunteer concerning the operational difficulty encountered:

____

____

____

____

Records:

d. Bypassing of sanitary sewers:

Who or what department investigated the problem: ____________

____

What happened? List circumstances, nature, and extent of

problem: ____

____

____

____

Where did problem occur? List location, type of area, (residential, commercial, industrial, etc.):

____

____

When did problem occur? List date, duration, frequency of

each occurrence, etc: ______________________________

____

What type of system was involved? List type of pipe material, age of pipe, type of joints, etc:

____

____

____

Why and how did problem occur? State your opinion as to why and in what manner the problem occurred, or the difficulty that was encountered:

Supplementary information: Describe the ground conditions, water conditions, etc., in the area in question:

State what corrective action, if any, was (or should be) taken to correct the situation:

List any other information you may care to volunteer concerning the operational difficulty encountered:

Records:

e. Overloaded pumping/lift stations:

Who or what department investigated the problem:

What happened? List circumstances, nature, and extent of problem:

Where did problem occur? List location, type of area (residential, commercial, industrial, etc.):

____

____

When did problem occur? List date, duration, frequency of

each occurrence: ______________________________

____

____

What type of system was involved? List type of pipe material, age of pipe, type of joints, etc:

____

____

____

Why and how did problem occur? State your opinion as to why and in what manner the problem occurred, or the difficulty that was encountered:

____

____

____

____

Supplementary information: Describe the ground conditions, water conditions, etc., in the area in question:

____

____

State what corrective action, if any, was (or should be) taken

to correct the situation: ______________________________

____

____

____

List any other information you may care to volunteer concerning the operational difficulty encountered:

____

____

____

____

Records:

f. Overloaded treatment plant:

Who or what department investigated the problem: ____________

____

What happened? List circumstances, nature, and extent of problem: ______________________________

____

____

____

Where did problem occur? List location, type of area, (residential, commercial, industrial, etc.):

____

____

When did problem occur? List date, duration, frequency of each occurrence, etc: __________________________

____

____

What type of system was involved? List type of pipe material, age of pipe, type of joints, etc:

____

____

Why and how did problem occur? State you opinion as to why and in what manner the problem occurred, or the difficulty that was encountered:

Supplementary information: Describe the ground conditions, water conditions, etc., in the area in question:

State what corrective action, if any, was (or should be) taken to correct the situation:

List any other information you may care to volunteer concerning the operational difficulty encountered:

Records:

g. Pavement cave-ins:

Who or what department investigated the problem:

What happened? List circumstances, nature, and extent of problem:

Where did problem occur? List location, type of area (residential, commercial, industrial, etc.):

When did problem occur? List date, duration, frequency of each occurrence, etc:

What type of system was involved? List type of pipe material, age of pipe, type of joints, etc:

Why and how did problem occur? State your opinion as to why and in what manner the problem occurred, or the difficulty that was encountered:

Supplementary information: Describe the ground conditions, water conditions, etc., in the area in question:

State what corrective action, if any, was (or should be) taken to correct the situation:

List any other information you may care to volunteer concerning the operational difficulty encountered:

Records:

h. Sewer clogging with sand/grit:

Who or what department investigated the problem:

What happened? List circumstances, nature, and extent of problem:

Where did problem occur? List location, type of area (residential, commercial, industrial, etc.):

____

____

When did problem occur? List date, duration, frequency of each occurrence, etc: __________________________

____

____

What type of system was involved? List type of pipe material, age of pipe, type of joints, etc:

____

____

____

Why and how did problem occur? State your opinion as to why and in what manner the problem occurred, or the difficulty that was encountered:

____

____

____

____

Supplementary information: Describe the ground conditions, water conditions, etc., in the area in question:

____

____

State what corrective action, if any was (or should be) taken to correct the situation:

____

____

____

List any other information you may care to volunteer concerning the operational difficulty encountered:

____

____

____

____

Records:

i. Other troubles:

Who or what department investgated the problem: ____________

____

What happened? List circumstances, nature, and extent of problem: ____________________________

____

____

____

Where did problem occur? List location, type of area, (residential, commercial, industrial, etc.):

____

____

When did problem occur? List date, duration, frequency of each occurrence, etc: ____________________________

____

____

What type of system was involved? List type of pipe material, age of pipe, type of joints, etc:

____

____

Why and how did problem occur? State your opinion as to why and in what manner the problem occurred, or the difficulty that was encountered:

Supplementary information: Describe ground conditions, water conditions, etc., in the area in question:

State what corrective action, if any, was (or should be) taken to correct the situation:

List any other information you may care to volunteer concerning the operational difficulty encountered:

12. List of Industries:

Name	Address	Type of Manufacture	Discharge in GPD

13. Water Supply:

Name: ______________________________

Name of Contact: ____________________Tel No. ____________

a. Are water consumption data available? Yes_______No_________

b. What form ______________________________

c. Can water usage of section of municipality be determined?

Yes___________No___________

14. Supplementary Reports and Data:

a. Master Plan available? Yes_______No_______

b. Zoning Map available? Yes_______No_______

c. Annual Reports available? Yes_______No_______

d. Previous infiltration/Inflow Studies available? Yes___No___

APPENDIX E

MANHOLE INSPECTION CHECK LIST

(Source: Elson T. Killam Associates)

Job No.____________________ Manhole No.___________________________

Location ____

Municipality ____________________ Crew ____________________________

Date ______________________ Time __________ Weather: Su H F R Sn C

Cover:
- ___Solid
- ___Ventilated
- ___Lock
- ___Bolted

Frame:
- ___Low
- ___Shifted
- ___Crooked
- ___Loose

Riser:
- ___Precast
- ___Block
- ___Brick
- ___Poor Joints
- ___Leaking

Corbell & Barrel:
- ___Precast
- ___Block
- ___Brick
- ___Poor Joints
- ___Leaking

Bench:
- ___Poured
- ___Brick
- ___Other
- ___Poor
- ___Missing
- ___Dirty

Channel:
- ___Poured
- ___Brick
- ___Pipe
- ___Poor
- ___Missing
- ___Dirty (Explain)

Main Line Up Stream:
- ___Size
- ___Depth of Flow
- ___Material
- ___Crooked
- ___Obstructed
- ___Dirty (Explain)

MainLine Down Stream:
- ___Size
- ___Depth of Flow
- ___Material
- ___Crooked
- ___Obstuctred
- ___Dirty (Explain)

Side Line Up Stream:
- ___Size
- ___Depth of Flow
- ___Material
- ___Crooked
- ___Obstructed
- ___Dirty (Explain)

Side Line Up Stream:
- ___Size
- ___Depth of Flow
- ___Material
- ___Crooked
- ___Obstructed
- ___Dirty (Explain)

Manholes:
- ___Height of Surchage above Invert
- ___Height of Ground Water above Invert

Steps: ___Broken
___Missing
___Worn

Comments: ____

____

____

____

____

____

APPENDIX F

STANDARDS FOR SELECTED SEWER PIPE AND APPURTENANCES
(Source: American Society of Testing & Materials-ASTM)

Condensed Title	Designation	Description
I. Asbestos-Cement Pipe		
Asbestos-Cement Non-Pressure Sewer Pipe	C-428	Material Specification--Non-pressure Sewer Pipe for conveying sanitary sewage in gravity-flow systems. Sizes 8 in. (20.32 cm) through 42 in. (1.07 m) in seven crush-strength designations of Class 1500, 2400, 3300, 4000, 5000, 6000, 7000.
Standard Definitions of Terms Relating to Asbestos-Cement and Related Products	C-460	Definitions of terms, alphabetically listed used in other ASTM Specifications on Asbestos-Cement products, including pipe.
Standard Methods of Testing Asbestos-Cement Pipe	C-500	Methods covering the testing of Asbestos-Cement pipe for hydrostatic strength, crushing strength and uncombined calcium hydroxide---for use in connection with the individual specifications for asbestos-cement pipe. (Flexural strength).
Linings for Asbestos-Cement Pipe	C-541	Requirements for plastic linings to be applied to asbestos-cement pipe, designed for special service in carrying corrosive fluids and in minimizing interior build-up on the pipe wall. Includes adhesion and chemical requirements, plus dimensional measurement requirements and method of determination.

Asbestos-Cement Non-Pressure Small Diameter Sewer Pipe	C-644	Material Specification - Non-Pressure sewer pipe for conveying sanitary sewage by gravity flow from point of occupancy to system of disposal. Sizes 4, 5, and 6 in. (10.2, 12.7 and 15.24 cm) three crush-strength designations of Class 1500, 2400, and 3300.
Rubber Rings for Asbestos-Cement Pipe	D-1869	Requirements for rubber rings used to seal the joints of asbestos-cement pipes, conforming to the various ASTM pipe Specifications. Covers chemical and physical requirements of both non-oil resistant and oil-resisitant rubber rings and methods of test.

II. Clay Sewer Pipe

Vitrified Clay Pipe, Extra Strength, Standard Strength and Perforated	C-700	Provides criteria for acceptance, including crushing strengths, hydrostatic tests, acid resistance, and dimension for sizes 3 - 42 in. (7.62 through 107 cm) diameter.
Testing Vitrified Clay Pipe	C-301	Describes equipment for, and methods of, testing clay pipe for crushing strength, absorption, hydrostatic capacity and acid resistance.
Compression Joints for Vitrified Clay Pipe and Fittings	C-425	Describes factory testing procedures and established acceptance criteria for clay pipe joints and jointing materials.
Installing Vitrified Clay Sewer Pipe	C-12	Describes methods of installation, correlates pipe strength to bedding practices and recommends backfilling practices.
Low Pressure Air Test of Vitrified Clay Pipe Sewer Lines 4 to 12 in. (10.2 to 30.5 cm).	C-828T	Describes procedures and criteria for air testing installed sewer lines.

III. Concrete Pipe

Plain Concrete Non-Pressure Sewer Pipe	C-14	Non-reinforced pipe sizes 4 to 36 in. (10.2 to 91.44 cm); three strength classifications.
Reinforced Concrete Non-Pressure Sewer Pipe	C-76	Reinforced pipe, sizes 12 in. (30.5 cm) up; five strength classifications.
Gasketed Joints for Circular Concrete Sewer Pipe	C-443	Gasket requirements, joint geometry, performance tests.
Concrete Manhole Sections	C-478	Requirements for standard pre-cast manhole components.
Standard Methods of Testing Concrete Pipe	C-497	Test methods referenced in standard pipe specifications.
Reinforced Concrete Arch Pipe	C-506	Reinforced pipe, arch shape, sizes 11 x 18 in. (28 x 46 cm) through 106 x 169 in. (269.24 x 429.3 cm) horizontal or vertical alignment; five strength classifications, each mode.
Reinforced Concrete Elliptical Pipe	C-507	Reinforced pipe, elliptical shape, sizes 14 x 23 in. (36 x 58.42 cm) through 115 x 181 in. (292.1 x 460 cm) horizontal or vertical alignment; five strength classifications, each mode.
Standard Definitions	C-822	Definitions of terms relating to concrete pipe and related products.
Reinforced Concrete D-Load Pipe	C-655	Reinforced pipe, sizes 12 in. (30.5 cm) up, with provision for design to meet specified load conditions.

IV. Plastic Pipe

A. Acrylonitrile-Butadiene-Styrene (ABS)

ABS Composite Pipe	D-2680	8-15 in. (20.32 - 38.1 cm) solvent-cemented and gasketed joint

		pipe, including quality control tests and installations.
ABS Sewer Pipe	D-2751	2-12 in. (5.1 - 30.5 cm) solvent-cemented and gasketed joint pipe, including quality control tests and installations.
ABS Solvent Cement	D-2235	Quality control for ABS cement.

B. Polyvinyl Chloride (PVC) Pipe

Type PSP PVC Sewer Pipe and Fittings	D-3033	Covers requirements and methods of test for materials, dimensions, workmanship, flattening resistance, impact resistance, pipe stiffness, extrusion quality, joining systems, and a form of marking for Type PSP PVC sewer pipe - 4-15 in. (10.2 - 38.1 cm) pipe.
Type PSM PVC Sewer Pipe and Fittings	D-3034	Covers requirements and methods of test for materials, dimensions, workmanship, flattening resistance, pipe stiffness, extrusion quality, joining systems, and a form of marking for the type PSM PVC sewer pipe - 4-12 in. (10.2 - 30.5 cm) pipe.
Rigid PVC Compounds and Chlorinated PVC Compounds	D-1784-69	This covers rigid plastic compounds composed of PVC, Chlorinated PVC, Vinyl Chloride copolymers, and the necessary compounding ingredients.
Standard Method of Test for Quality of Extruded PVC Pipe by Acetone Immersion	D-2152-67	This method covers the determination of the quality of extruded rigid PVC as indicated by reaction to immersion in anhydrous acetone.
Solvent Cements for PVC Plastic Pipe and Fittings	D-2564-73a	Provides general requirements for PVC solvent cements to be used in joining PVC pipe and socket-type fittings.

Making Solvent-Cement Joints with PVC Pipe and Fittings	D-2855-73	A procedure is described for making joints with PVC pipe, both plain end and fittings, and bell ends, by means of solvent cement.
Bell End PVC Pipe	D-2672-73	Covers bell-end PVC pipe made in standard thermoplastic pipe dimension ratio and schedule 40 sizes; pipe is pressure rated for water.

C. Standards Applicable to All Plastic Pipe

Standard Recommended Practice for Underground Installation of Flexible Thermoplastic Pipe	D-2321-72	This recommended practice describes procedures for installing single-wall thermoplastic sewer pipe in excavated trenches. These installation procedures are predicated on the assumption that the pipe will perform in accordance with "flexible conduit" theories.
External Loading Properties of Plastic Pipe by Parallel-Plate Loading	D-2412-72	Covers the determination of load-deflection characteristics, calculation of stiffness factors, and measurement of the load and deflection at rupture of plastic pipe under parallel-plate loading.
Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (Falling Weight)	D-2444-70	Covers the determination of the energy required to produce failure in thermoplastic pipe of fittings under specified conditions of impact by means of a tup (falling weight).
Flexible Plastic Sewer Pipe Joints	D-3212	Quality control for gasketed pipe joints.
Plastic Pipe Dimensions	D-2122	Measuring plastic pipe.
Conditioning Plastics and Electrical Insulating Material for Testing	D-618-61	These methods define procedures for conditioning plastics and electrical insulating material prior to testing, and the conditions under which they shall be tested.

	Standard Definitions of Terms Relating to Plastics	D-883-73a	A compilation of definitions and technical terms used in the plastics industry, terms that are generally understood or adequately defined in other readily available sources.
V.	Corrugated Steel Pipe	(ASTM designation is not available for corrugated steel pipe for sewers)	Federal Specifications---corrugated Steel Pipe Class I, Series A and B describes circular pipe with annular 3 x 0.5 in. (7.62 x 1.3 cm) and 3 x 1 in. (7.62 x 2.54 cm) corrugations. Coating Types G, H, and J describe asbestos-protected, asphalt-coated, paved or lined respectively. Use Federal Construction Guide Specification 02501 Section 14 for tests to qualify joint for watertight requirements specified in this document.